

Solar Energy

NOTICE

This report was prepared to document work sponsored by the United States Government. Neither the United States nor its agents the United States Department of Energy, the United States National Aeronautics and Space Administration, nor any federal employees, nor any of their contractors, subcontractors or their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product or process disclosed, or represent that its use would not infringe privately owned rights.

1 REPORT NO. DOE/NASA CR-150686	2 GOVERNMENT ACCESSION NO.	3 RECIPIENT'S CATALOG NO.	
4 TITLE AND SUBTITLE Prototype Solar Heating and Combined Heating and Cooling Systems (Quarterly Report)		5 REPORT DATE 1 October 1976	6. PERFORMING ORGANIZATION CODE
		8. PERFORMING ORGANIZATION REPORT #	
7. AUTHOR(S)		10 WORK UNIT NO.	
9. PERFORMING ORGANIZATION NAME AND ADDRESS General Electric Company - Space Division Post Office Box 8661 Philadelphia, Pennsylvania 19101		11. CONTRACT OR GRANT NO. NAS8-32092	
		13 TYPE OF REPORT & PERIOD COVERED Contractor Report July 76 - September 76	
12 SPONSORING AGENCY NAME AND ADDRESS National Aeronautics and Space Administration Washington, D. C. 20546		14 SPONSORING AGENCY CODE	
15 SUPPLEMENTARY NOTES This work was accomplished under the technical management of Mr. William L. Moore, George C. Marshall Space Flight Center, Alabama.			
16. ABSTRACT The General Electric Company is developing eight prototype solar heating and combined heating and cooling systems. This effort includes development, manufacture, test, installation, maintenance, problem resolution, and performance evaluation. All cost data have been removed from this report.			
17 KEY WORDS		18 DISTRIBUTION STATEMENT Unclassified-Unlimited	
		 WILLIAM A. BROOKSBANK, JR. Mgr, Solar Heating and Cooling Project Office	
19 SECURITY CLASSIF. (of this report) Unclassified	20 SECURITY CLASSIF. (of this page) Unclassified	21 NO. OF PAGES 117	22 PRICE NTIS

TABLE OF CONTENTS

<u>SECTION</u>	<u>Page</u>
INTRODUCTION	
PART I - SUMMARY	
1.1 Cost	1-1
1.2 Schedules	1-2
1.3 Technical Performance	1-2
1.4 Variances	1-5
PART II - COST	2-1
PART III - SCHEDULES	3-1
PART IV - TECHNICAL PERFORMANCE	
1. Task 1.1 - Management	4-1
1.1 Program Directions (WBS 1.1.1).....	4-1
1.2 Program Planning and Control (WBS 1.1.2).....	4-3
1.2.1 Program Control.....	4-3
1.2.2 Data Management.....	4-5
1.2.3 Change Control.....	4-6
1.3 Quality Assurance (WBS 1.1.3).....	4-6
2. Task 1.2 - System Development.....	4-7
2.1 Introduction.....	4-7
2.2 Analysis and Integration (WBS 1.2.1).....	4-7
2.2.1 Baseline System Configurations (Heating-Only Systems).. 2.2.1.1 Single-Family Heating Baseline System Configuration.....	4-8 4-8
2.2.1.2 Multi-Family Heating Baseline System Configuration.....	4-13
2.2.1.3 Commercial Heating Baseline System Configuration.....	4-17
2.2.1.4 Baseline System Summary.....	4-17
2.2.1.5 Trade Studies.....	4-22
2.2.1.6 Economics.....	4-29
2.2.2 Systems Analysis of Heating and Cooling Systems.....	4-32
2.2.2.1 SDHP Analysis.....	4-34
2.2.2.2 Heat Pump Configurations.....	4-37
2.2.2.3 LTR System Analysis Code.....	4-37
2.2.2.4 Heating and Cooling System Trades.....	4-39
2.3 Task 2200 - System Development.....	4-41
2.3.1 Heating Systems.....	4-41
2.3.1.1 Collectors.....	4-41
2.3.1.1.1 Collector Design and Performance Verification.....	4-41 4-41
2.3.1.1.2 Collector Integration.....	4-45
2.3.1.1.3 Collector Primary Loop.....	4-52

TABLE OF CONTENTS (Cont.)

<u>SECTION</u>		<u>Page</u>
	2.3.1.2 "All Other" Components, Heating Systems.....	4-56
	2.3.1.3 Space Heating/Cooling.....	4-57
	2.3.1.4 Auxiliary Energy Subsystem.....	4-58
	2.3.1.5 Hot Water Subsystem.....	4-58
	2.3.1.6 Energy Transport Subsystem.....	4-58
	2.3.1.7 Controls Subsystem.....	4-59
	2.3.1.8 Electrical Subsystem.....	4-65
	2.3.1.9 System Integration.....	4-69
2.3.2	Heating and Cooling Systems.....	4-71
	2.3.2.1 Collectors.....	4-71
	2.3.2.2 Energy Storage Subsystem.....	4-71
	2.3.2.3 Space Heating Subsystem.....	4-71
	2.3.2.4 Auxiliary Energy Subsystem.....	4-71
	2.3.2.5 Hot Water Subsystem.....	4-71
	2.3.2.6 Energy Transport Subsystem.....	4-71
	2.3.2.7 Controls Subsystem.....	4-71
	2.3.2.8 Electrical Subsystem.....	4-71
	2.3.2.9 System Integration.....	4-71
	2.3.2.10 Task 2200 - Cooling Subsystem.....	4-71
2.4	Task 2300 - Test.....	4-87

LIST OF ILLUSTRATIONS

<u>No.</u>	<u>TITLE</u>	<u>Page</u>
PART I - SUMMARY		
1-1	Master Program Plan	1-3
1-2	Cost of Solar Energy Delivered - Single Family Home, Madison, Wisc.	1-5

PART II - COST

This section has been deleted

PART III - SCHEDULES

3-1	Master Program Plan	3-3
3-2	WBS Element Schedule and Status	3-4
3-3	Data Requirements Status	3-5

LIST OF ILLUSTRATIONS (Cont.)

<u>No.</u>	<u>TITLE</u>	<u>Page</u>
PART IV - TECHNICAL PERFORMANCE		
1.1-1	Program Organization	4-2
2.2-1	Standard Symbols used on System Schematics (From S30014).....	4-9
2.2-2	System Schematic, Heating Single Family System	4-10
2.2-3	Supply/Demand Profile (Heating Single Family; Madison '68 Weather)	4-12
2.2-4	System Schematic, Heating Multi-Family System	4-14
2.2-5	Supply/Demand Profile (Heating Multi-Family; Madison '68 Weather)	4-16
2.2-6	System Schematic, Heating Commercial System	4-18
2.2-7	Supply/Demand Profile (Heating Commercial; Madison '68 Weather)	4-20
2.2-8	System Configuration No. 1	4-23
2.2-9	System Configuration No. 2	4-23
2.2-10	System Configuration No. 5	4-24
2.2-11	Effect of Configuration - Multi-Family Residence	4-24
2.2-12	Effect of TES Temperature - Energy Delivered to SF Home, Madison	4-26
2.2-13	Effect of Storage Volume - Single Family Residence	4-26
2.2-14	Influence of HX-1 Size on System Performance	4-27
2.2-15	Recirculating vs. One-Pass Heat Exchanger for DHW	4-28
2.2-16	Cost of Solar Energy Delivered - Single Family Home, Madison, Wisconsin	4-30
2.2-17	Cost of Solar Supplied Energy - Multi-Family Residence, Madison, Wisconsin 1968	4-30
2.2-18	Cost of Solar Energy - Commercial Building, Madison, Wisconsin	4-32
2.2-20	Fraction of Season Cooling Load Supplied by the SDHP (η)	4-35
2.2-21	Solar Rankine Seasonal Performance Factor	4-36
2.2-22	Solar Rankine Heat Pump for Heating Mode	4-36
2.2-23	LTR System Analysis Code	4-38
2.3-1	Shroud Test Data	4-44
2.3-2	Temperature Profile (Zero Flow, 0° Declination)	4-48
2.3-3	Energy Emitted from the Inner Glass Tube per Ft ² of Tube Surface vs. Time of Day	4-49

LIST OF ILLUSTRATIONS (Cont.)

<u>No.</u>	<u>TITLE</u>	<u>Page</u>
PART IV - TECHNICAL PERFORMANCE		
2.3-4	Temperature Profile (Zero Flow, 0° Declination.....	4-50
2.3-5	Energy Emitted from the Inner Glass Tube per Ft ² of Tube Surface vs. Time of Day.....	4-51
2.3-6	Least Restrictive Solar Loop.....	4-55
2.3-7	Subsystem Concepts - "All Other".....	4-56
2.3-8	Direct Solar Heating (HSF).....	4-60
2.3-9	Solar Boost (HSF).....	4-60
2.3-10	Heating from Storage (HSF).....	4-61
2.3-11	Storage Boost Heating.....	4-61
2.3-12	Storing Solar Energy.....	4-62
2.3-13	Direct Solar Heating from TES (HMF & COMM).....	4-62
2.3-14	Energy Storage.....	4-63
2.3-15	Stored Energy Use (HMF & COMM).....	4-63
2.3-16	Auxiliary Energy Use (HMF & COMM).....	4-64
2.3-17	Controls Subsystem Block Diagram (Typical for All Heating-Only Systems.....	4-64
2.3-18	Electrical Diagram, HSF System.....	4-66
2.3-19	Electrical Diagram, HMF System.....	4-67
2.3-20	Electrical Diagram, HCOM System.....	4-68
2.3-21	Schematic Diagram of S/EDHP (Cooling Mode).....	4-72
2.3-22	LTR Fluid Selection.....	4-74
2.3-23	Three Ton LTR Loop Schematic (95°F Day).....	4-77
2.3-24	Ten Ton LTR Loop Schematic (95°F Day).....	4-77
2.3-25	Three Ton S/EDHP Air Cooled (SF) Layout.....	4-79
2.3-26	Three Ton S/EDHP Air Cooled (SF).....	4-80
2.3-27	Ten Ton (Water Cooled) S/EDHP.....	4-80
2.3-28	Ten Ton S/EDHP Air Cooled (MF/COM).....	4-81
2.3-29	Ten Ton (Air Cooled) S/EDHP.....	4-81
2.3-30	Heat Pump Performance and Requirements.....	4-82
2.3-31	LTR Off Design Performance.....	4-82
2.3-32	LTR/HP Matched Operation.....	4-83
2.3-33	Three Ton LTR/HP Matched Operating Points.....	4-83
2.3-34	Three Ton LTR/HP Matched Operating Speed.....	4-84
2.3-35	Effect of Speed Limitations on Matched Operation Map... Open-Shift Compressor.....	4-84 4-86
2.4-1	Solar Collector Test Facility.....	4-88
2.4-2	Solar Insulation Sensor Data.....	4-89
2.4-3	LTR Test Loop.....	4-90
2.4-4	System Test Facility.....	4-90

LIST OF TABLES

<u>No.</u>	<u>Title</u>	<u>Page</u>
PART I - SUMMARY		
1-1	Deleted	1-1
1-2	Program Variances (From Plan Based on Negotiated Program)	1-6
PART IV - TECHNICAL PERFORMANCE		
2.2-1	Single Family System Description	4-11
2.2-2	Multi-Family System Description	4-15
2.2-3	Commercial System Description	4-19
2.2-4	Prototype System Summary - Heating Only Systems	4-21
2.2-5	Sample of Solar Driven Machines Analyzed	4-38
2.3-1	Mounting Situation Summary	4-46
2.3-2	Fluids Option Matrix	4-53
2.3-3	Design Alternative Merit Rating - Thermal Energy Storage - Medium Selection	4-58
2.3.4	LTR Fluid Selection.....	4-76
2.3.5	1st Cycle Baseline Heat Pump Hardware.....	4-85

INTRODUCTION

The Quarterly Status Report (Data Requirements Item No. 500-10) provides a summary of the cost, schedule and technical progress of the program. Since it includes and extends the information included in the Monthly Status Reports (Data Requirements Item No. 500-11) it also meets the contract requirement of a monthly status report. It is supplemented by the financial status report (Data Requirements Item No. 500-27) submitted under separate cover.

The report format is:

- Part I - Summary
- Part II - Cost
- Part III - Schedules
- Part IV - Technical Performance

The report is integrated with the program management systems being used on the program, so, where possible, multiple use of program data such as schedules or financial status reports has been accomplished.

PART I

SUMMARY

PART I - SUMMARY

1.1 Cost

This paragraph has been deleted.

1.2 Schedules

The working program schedule is posted on the walls of the Program Control Room and is used to monitor program status at "standup" meetings held three times a week. Reviews with GE management are held in the Control Room to take advantage of the detail schedule data base. The schedules were briefly reviewed at the Quarterly Review held at the end of this report period. A summary schedule is shown in Figure 1-1.

Definition of the Operational Test Sites is a schedule problem that becomes more significant with time. Detail design of the heating systems is site dependent and it was planned to make the Qualification System similar to one of the prototypes. Replanning of the program in this area will be accomplished when site designation dates are established. This point will be discussed with NASA-MSFC. At this time, the hardware delivery dates are not in jeopardy and System Qualification can proceed for a representative system.

1.3 Technical Performance

Program technical status is reflected by the achievement of the key milestone: PDR Heating Systems at the end of the report period and the material on Heating and Cooling Systems presented at the Quarterly Review. The presentation material and handouts at the meeting describe the technical accomplishments. Selected material has been included in Part IV of this report. Highlights of the technical accomplishments are as follows.

WBS 1.1.1	Program Direction	An effective program team has been assembled and is working. Communications with NASA-MSFC and GE management have been maintained.
WBS 1.1.2	Program Planning & Control	Detail schedules have been established and all data submittals have been accomplished.

This page has been deleted.

WBS 1.1.3	Quality Assurance	Quality Assurance Plan issued.
WBS 1.2.1	Analysis and Integration	Heating system configurations established and performance analyzed. System sizing technique established. Heating and cooling analytical tools developed and used to analyze performance. Detailed model of solar Rankine engine established. Two sizes of heat pump selected for development.
WBS 1.2.2.1.1	Solar Collector Development	Engineering design released. Integration and solar collector loop studies initiated.
	"All Others"	Components identified and performance requirements investigated for Heating Only Systems.
WBS 1.2.2.1.7	Controls	Heating system control modes identified and approach established.
WBS 1.2.2.1.10	System Integration	An approach to specification of Prototype systems established.
WBS 1.2.2.2.11	S/E Driven Heat Pump	First cycle hardware approach defined. Configuration concepts established. Initial performance maps prepared. Solar compressor design approach established.
WBS 1.2.3	Test	Facilities plans. Insolation sensor tests.

The PDR generated much discussion and some challenges to the material presented. One such area was the economics of the systems and comparative costs of solar energy. A typical curve from Part IV is shown on Figure 1-2. Many important concepts are included in this analysis and it is planned to discuss this topic further with NASA-MSFC to ensure that successful communication has been accomplished. The comparative costs are very much a function of the energy cost scenario used which is to be investigated by NASA-MSFC.

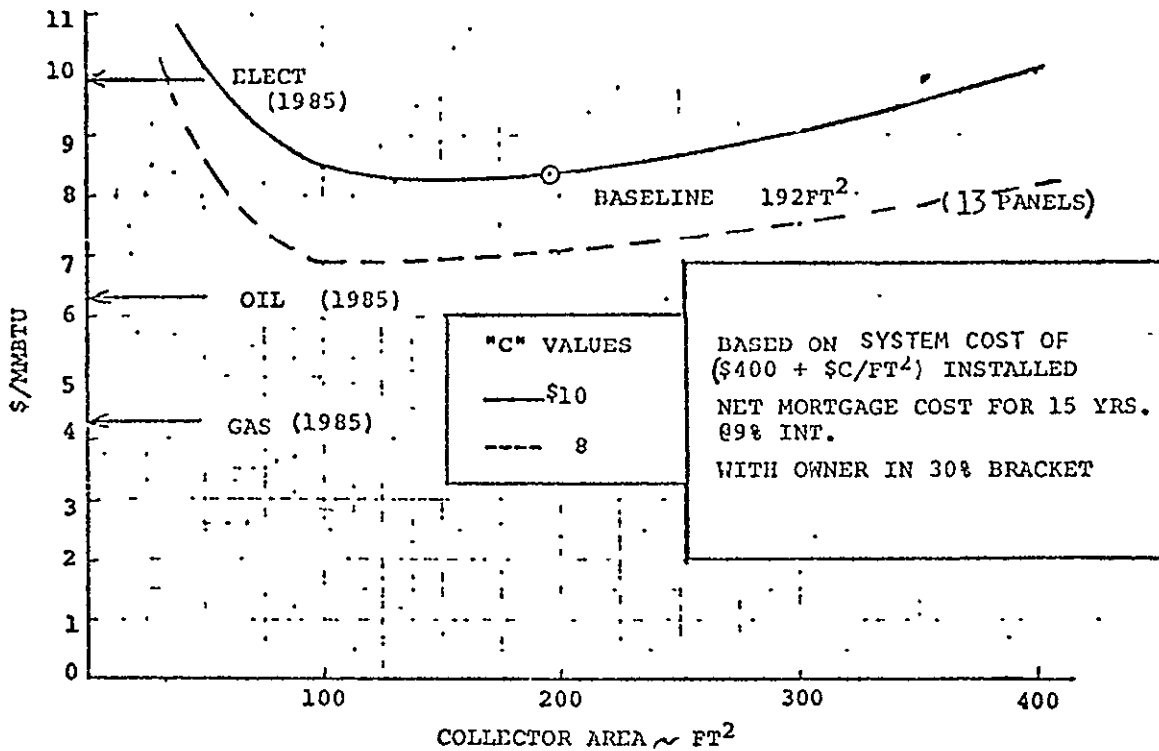


Figure 1-2 Cost of Solar Energy Delivered - Single Family Home, Madison, Wisc.

Another area of great interest was collector selection and performance. This is discussed in Part IV and in Review Item Discrepancies being submitted to complete the PDR.

GE believes it has established high efficiency system configurations that are compatible with a variety of auxiliary energy sources. These configurations, coupled with the cost effective tubular collectors, will provide solar heating systems that will rank with the best that can be built in the time frame of this program.

1.4 Variances

Requested variance data is summarized in Table 1-2.

ORIGINAL PAGE IS
OF POOR QUALITY

Table 1-2 - PROGRAM VARIANCES
(FROM PLAN BASED ON NEGOTIATED PROGRAM)

TYPE OF VARIANCE			REASON FOR VARIANCE	IMPACT ON TASK	IMPACT ON CONTRACT	CORRECTIVE ACTION
COST	SCHED	PERF				
X			Linear Manpower Build-Up.	1.1	None	Effort deferred to next period when management needs are increased.
X	X		Delayed Start-up of Subcontractors	1.2.1 and 1.2.2.2.11	None	Effort rescheduled and, in some cases, reassigned.
X	X		Deferral of effort on economics analysis	1.2.1 (delay of economics analysis)	None	Effort rescheduled.
X	X		Facility Not available	1.2.3 (Collector tests)	None	Rescheduled after facility upgrade.
X	X		Analytical tools not available (expander and controls)	1.2.2.11	None	Compress schedule. Additional manpower assigned.

PART II

COST

Part II - Cost has been deleted.

PART III
SCHEDULES

~~THIS PAGE BLANK NOT FOR~~

PART III

SCHEDULES

Summary program schedules are shown in Figures 3-1, 3-2, and 3-3. These are extracted from the detailed program working schedules posted in the Control Room at Valley Forge.

Figure 3-1 is a Master Program Plan. The principal program key event during this period - the heating systems PDR was completed per the schedule. Development of the small and large Solar/Electric Driven Heat Pumps was initiated in the expander area. This activity is slightly behind scheduled accomplishments, but work around plans have been generated. As noted in Part II, material expenditures are significantly under budget. Design of the heating systems has reached the point where Operational Test Site designation would allow detailed design to proceed. Analysis of the heating and cooling systems is underway. The anticipated level of accomplishment in tradeoffs and economics analysis was not achieved as development of analytical tools took longer than anticipated. The tools are now available and emphasis is being placed on catching up in this area. Facilities design is proceeding. The designator 4070 in the schedule refers to an internal approval document for GE funded facilities. The system test facility expenditure is approved and approval to order the equipment for collector manufacturing has been obtained. The total investment approval has been rescheduled for the fourth quarter because of the time required for review and approval of a major addition to the Valley Forge facility.

Figure 3-2 is the schedule for the WBS elements. All scheduled tasks have been started and the major milestone, the PDR, achieved.

Figure 3-3 shows the data deliveries. During this period all scheduled items were delivered.

Scheduled events related to the Operational Test Sites will not occur during the next period as planned because the sites have not been identified. This has a significant impact on activities planned during the rest of 1976 and will result in replanning a portion of the program. It is planned to discuss this problem with NASA-MSFC.

PAR FORM 21

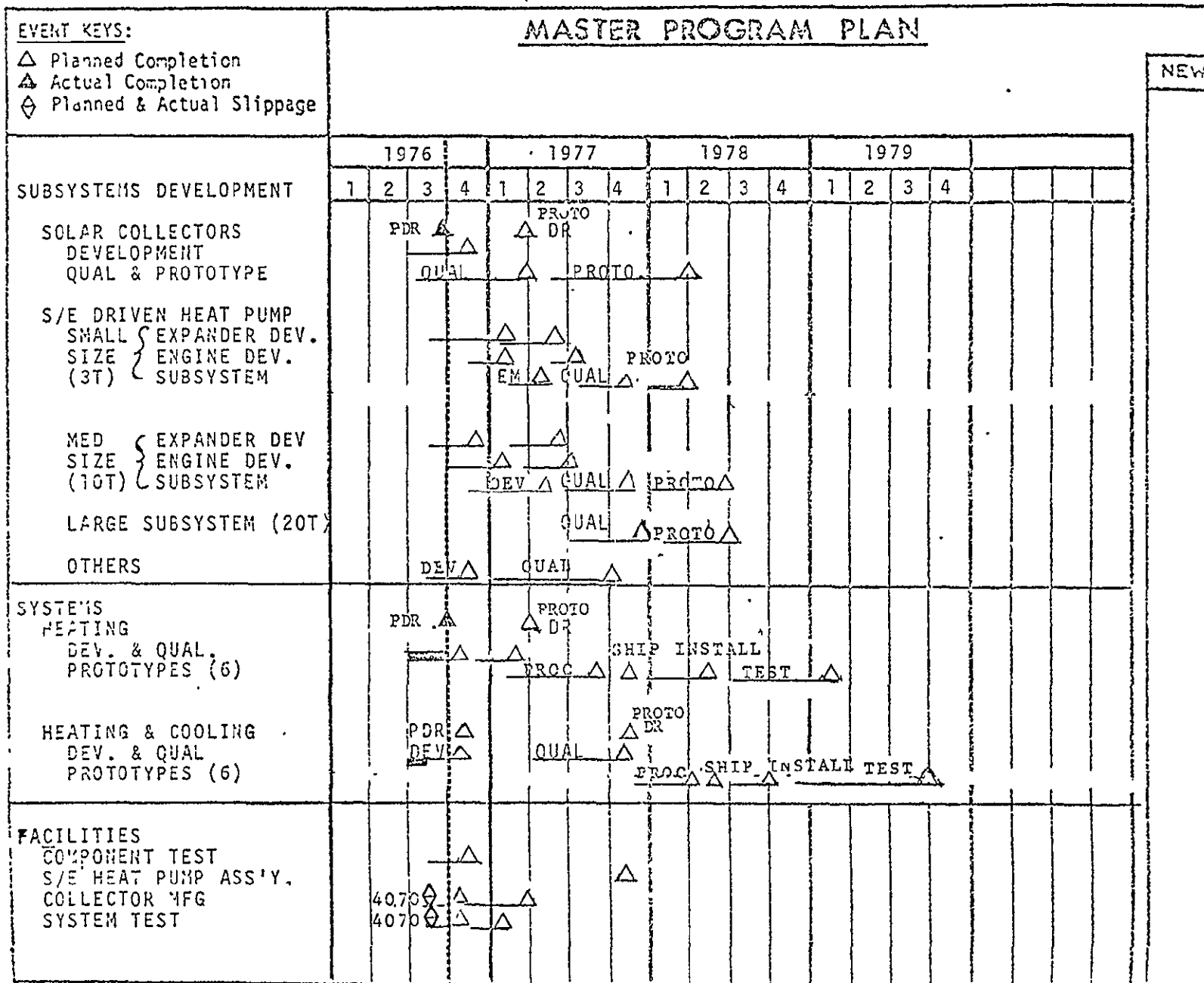


Figure 3-1. Master Program Plan

ORIGINAL PAGE IS
OF POOR QUALITY

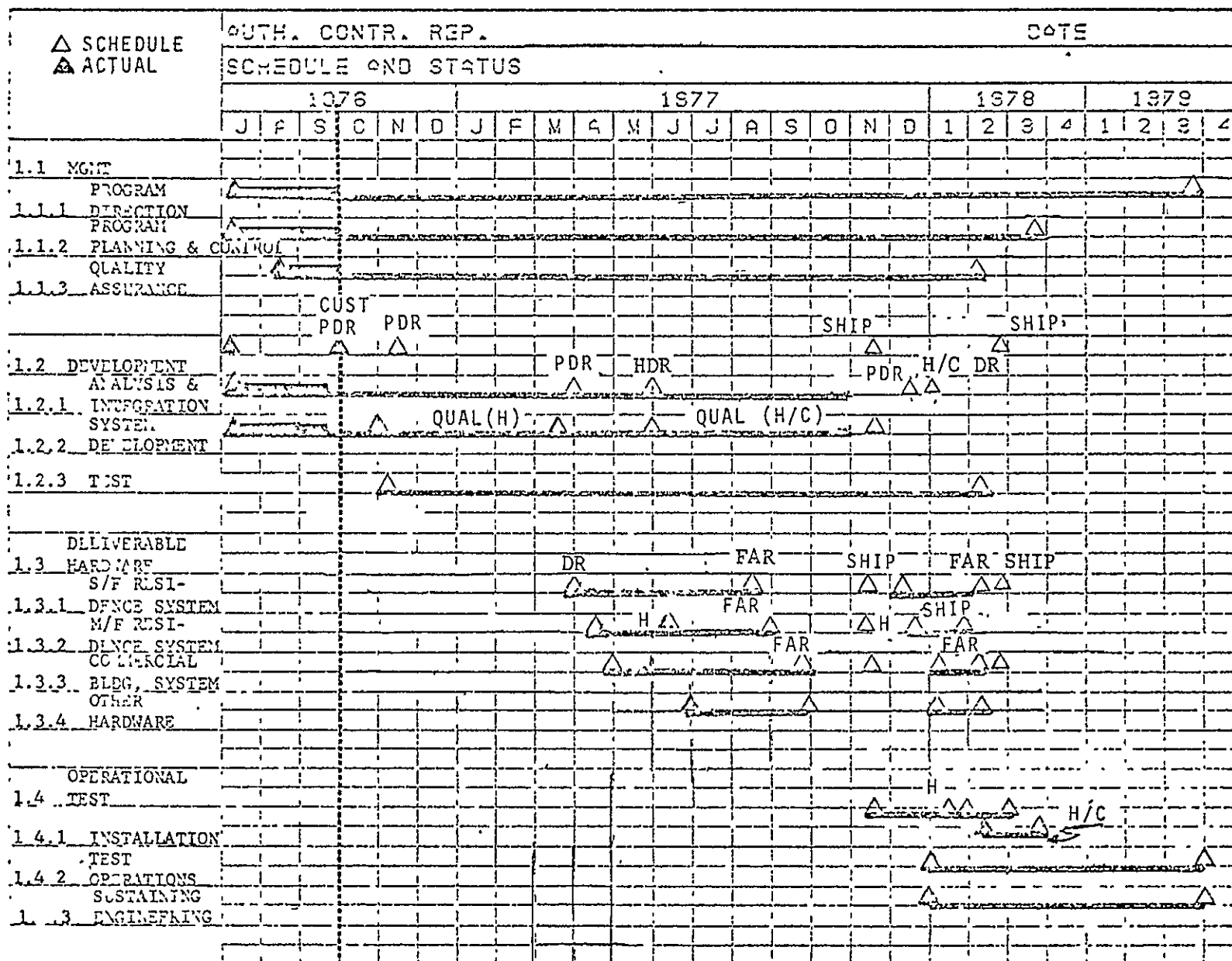


Figure 3-2. WBS Element Schedule and Status

[illegible]

Figure 3-3. Data Requirements Status

PART IV
TECHNICAL PERFORMANCE

SECTION 1

TASK 1.1 - MANAGEMENT

1.1 PROGRAM DIRECTIONS (WBS 1.1.1)

During this period the Program Manager (Mr. J. C. Graf) and his Deputy (Mr. K. L. Hanson) initiated the program and coordinated it with the activities underway on July 1 such as the TC-100 solar collector development. A major activity was staffing and organizing the program team. At the end of the period the organization shown in Figure 1.1-1 was in place and operating. An initial plan for approval and authorization of material expenditures was in place and working.

Three major customer coordination events were held this period to supplement the frequent telephone and liason (W. Buck) contacts with MSFC. The first, a technical kickoff meeting, was requested by GE and held at Valley Forge on 7/22 and attended by Messrs. Bowden, Marshall and Moore. Its primary purposes were to provide an update on the status of the TC-100 solar collector and identify initial program directions with respect to analysis and development.

The second event, a programs integration meeting held at MSFC on 8/3/76, was a result of the technical kickoff meeting which identified several issues that cut across several of the MSFC programs. These include:

1. Energy cost increase scenario
2. Use of standard weather data for analyses
3. Economics analysis techniques
4. Building models for use prior to identification of operational test sites

The primary results of this meeting were that MSFC would evaluate the need for program direction in these areas but the contractors should proceed using their

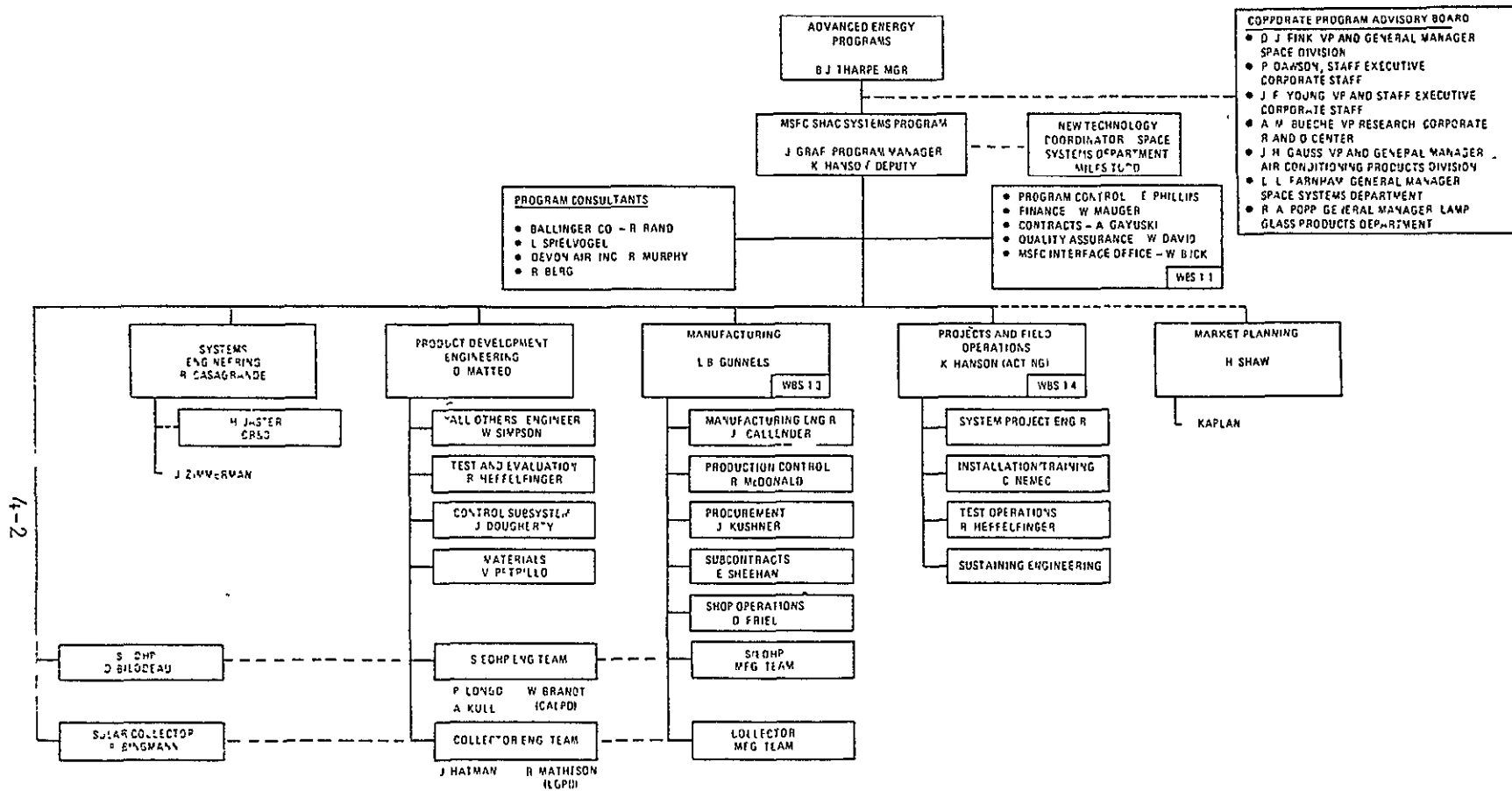


Figure 1.1-1. Program Organization

ORIGINAL PAGE IS
OF POOR QUALITY

own data bases and judgements.

The third event was the PDR on Heating and Hot Water Systems/Quarterly Program Review held at Valley Forge on 9/29 and 9/30. The results of the PDR are included in a formal set of minutes submitted to NASA-MSFC on 10/8/76.

Internal GE meetings to assess and report program status included a PAR (Program Analysis Review)* with Valley Forge management (the Department General Manager, Mr. L. L. Farnham, and the Vice President and Division General Manager, Mr. D. J. Fink.). A program technical review was held on August 31 and a program review with Mr. Farnham and his staff on 9/21/76. An internal design review of the PDR material was held on 9/24/76.

1.2 PROGRAM PLANNING AND CONTROL (WBS 1.1.2)

1.2.1 PROGRAM CONTROL

The program approach was documented in a Development Plan and a Verification Plan which were prepared and submitted to NASA-MSFC. These plans are extensions of the plans originally submitted with the proposal and were updated to reflect current program approaches.

The basic program control tool being used on this program is the Control Room. It was established during this period and the schedule of key milestones and program activities posted on large scale schedules. These represent the official program schedule against which technical status and progress is measured. Schedule data required for monthly, quarterly, and management reports is

* The PAR acronym refers to an established GE formal internal program review policy in which key programs are reviewed at regular intervals.

extracted from the Control Room postings. Individual task sections of the Control Room schedule are monitored and maintained by the responsible task leaders. Program status is reviewed three times per week (Monday, Wednesday and Friday) at "standup" meetings attended by the task leaders and the program management staff. Problems and interactions are identified and resolved at these meetings by the assignment of action items which are posted and monitored in the Control Room.

In the budgets area the program operated on the basis of the proposed expenditure profile as modified to meet the funding restraints added in discussions with NASA-MSFC. Within the first few weeks it became apparent the expenditure rate was significantly below the "negotiated baseline". This continued through July and August because personnel were added to the program selectively and as they could be efficiently assimilated. Manpower budgets were established by functional or task leader teams in July and used for program staffing and early budgets. The need for a modified expenditure profile was identified and the activity to generate same was initiated on a low priority basis. It was considered more important to staff the program team than to generate an updated expenditure profile. However, both have been accomplished and the updated expenditure profile is being used in this report.

Suggested changes to the Work Breakdown Structure were submitted to NASA-MSFC in July and have been approved per a letter from C. Dorning dated 8/30/76. The changes are minor, primarily cosmetics, and make the WBS more adaptable to the use of heat pumps for both heating only and heating and cooling systems. Of more substance is the fact that the system configuration and hardware elements leads to subsystem definitions that are not included in the current WBS. For example the current Heating-Single Family configuration has a functional

subsystem that includes elements of the WBS defined Energy Storage, Space Heating/Cooling, and Energy Transport Subsystems. This functional subsystem which can be described as the secondary energy loop has no exact counterpart in the contract WBS. This is not a major problem but shows that the system/subsystem/component breakdown does not provide the conventional practice of functional groupings. The program approach being followed is to use the contract defined WBS structure for cost accounting and budgets and carry out the engineering required by the grouping of functionally related components. Responsibility for the contract WBS items will be grouped, as appropriate, for the assignment of responsibilities to the program staff. We have found it convenient to use the term "All Others" to refer to several of the subsystem/components that are of a near conventional nature, e.g., pumps, domestic hot water subsystems, auxiliary energy source, etc.

1.2.2 DATA MANAGEMENT

The scheduled data submittals completed during this period are as follows:

Data Requirements No.

1	Development Plan (Update)
2	Verification Plan (Update)
3	Quality Assurance Plan
4	System Performance Specifications (Updated, Preliminary)
7	PDR Data Package
11	Monthly Status Reports (2)
15	Special Handling, Installation and Maintenance Tools List
18	Hazards Analyses

ORIGINAL PAGE IS
OF POOR QUALITY

Data Requirements No.

22	Logistics Plan (Heating Only)
24	Safety and Health Plan
25	New Technology Reporting Plan (Approved)
26	WBS and Dictionary (Update)
26	Financial Management Report (2)

Comments on the Safety and Health Plan have been received and are being incorporated into the Plan. During the PDR, GE and NASA-MSFC Quality Assurance Personnel had a sidebar meeting on the Quality Assurance Plan which resulted in agreement on minor changes. These are being incorporated and an updated plan will be forwarded to NASA-MSFC by the end of October.

1.2.3 CHANGE CONTROL

An internal procedure for tracking and controlling changes to contractual and controlled documents was established within the program. The first change, designated CP-001, was processed through the system on 9/9/76 and is being reviewed by NASA-MSFC. It relates to suggested revisions to the Statement of Work, an action item from the technical kickoff meeting.

1.3 QUALITY ASSURANCE (WBS 1.1.3)

The major activity this period was the preparation of the Quality Assurance Plan and discussing it with NASA-MSFC. The responsibility for Program Quality Assurance was assigned to W. David, who joined the program as planned in time to prepare the Plan.

SECTION 2

TASK 1.2 - SYSTEM DEVELOPMENT

2.1 INTRODUCTION

The major program activity this period was in WBS Task 1.2 - System Development and key results are presented in this section, organized by WBS element.

2.2 ANALYSIS AND INTEGRATION (WBS 1.2.1)

Systems analyses activities were directed toward identifying and verifying the "best" system configuration for the heating systems and to support heating and cooling design studies.

Review of the studies conducted during the proposal lead to the conclusion that the case studies for Madison needed to be modified and extended to lay the foundation for marketable solar heating systems. Climate and demographics make the Washington-New York-Boston area a significant market area so analyses of system performance in these areas was planned. Results for the Washington, D.C. area are included in this report. In addition, the building loads were modified to include the effects of thermal capacity and to include the effects of insulation to the standards of ASHRE 90-75.

In order to prepare for proceeding with design of the systems for the Operational Test Sites an approach to system specifications was developed and systems for Madison, Wisconsin defined for the PDR.

The order of presentation of the systems material is as follows:

- a) Baseline heating systems configurations and their performance
- b) Trade studies carried out to establish and verify the heating system configuration.
- c) Heating and cooling systems analysis.

ORIGINAL PAGE IS
OF POOR QUALITY

2.2.1 BASELINE SYSTEM CONFIGURATIONS (HEATING - ONLY SYSTEMS)

During the reporting period PDR baseline system configurations were identified for the SF, MF, and COMM heating only systems. These baseline systems are presented in the following paragraphs. Symbols used on the system schematics are identified in Figure 2.2-1. In addition, system operating modes were defined for each of the baseline systems and are included in the Controls portion of this report (paragraph 2.3.1.7).

2.2.1.1 Single-Family Heating Baseline System Configuration

The baseline configuration for the single-family heating system is shown in schematic form as Figure 2.2-2. Hardware and performance details for this system are summarized in Table 2.2-1. Primary features of this system are as follows:

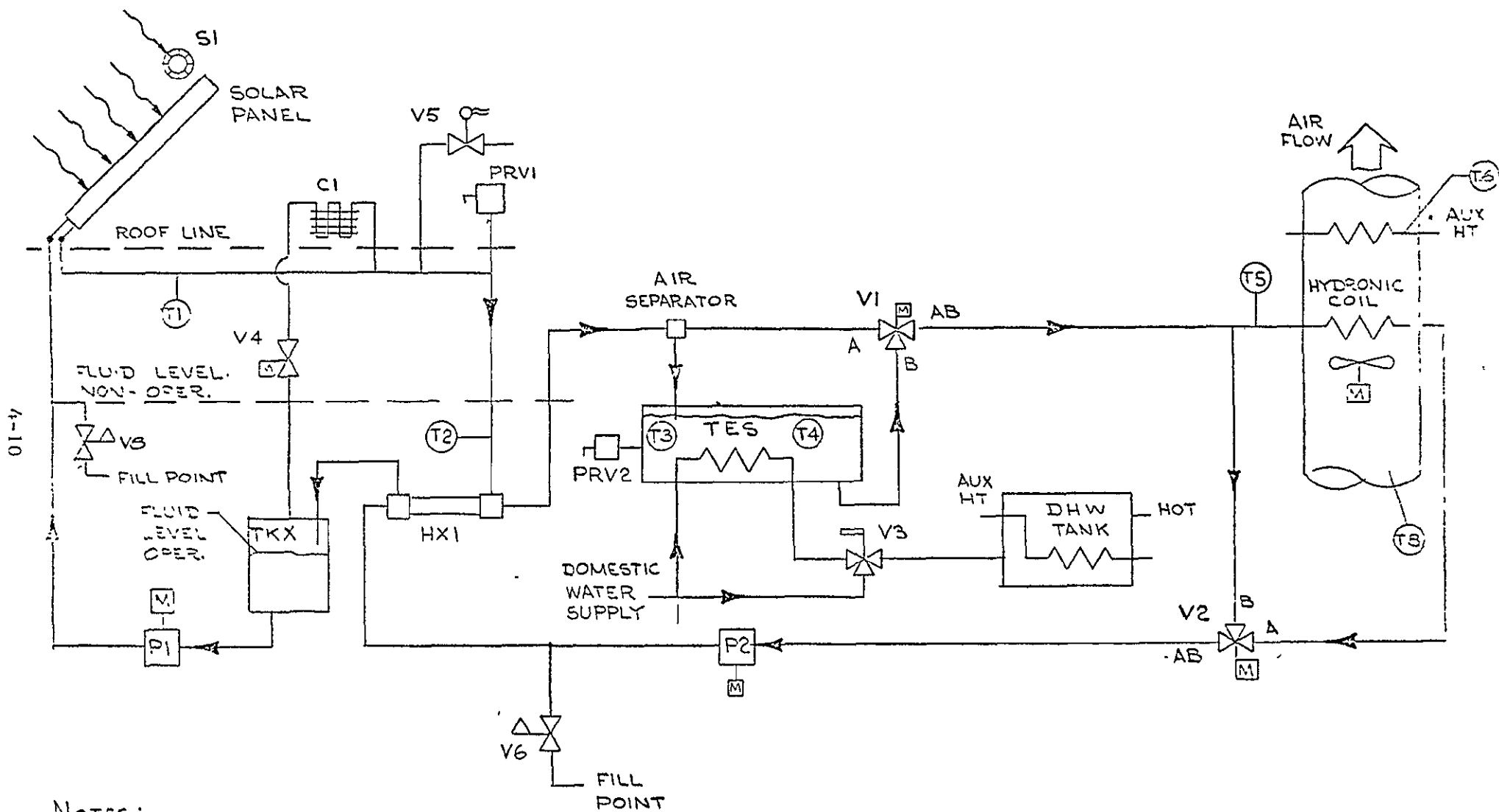
1. Solar energy for space heat provided by circulated heated water through a hydronic coil located in an air handler for a hot air heating system.
2. Circulating heated water can come from the solar loop heat exchanger (HX1) directly to the coil, or from the storage tank. The storage tank can be charged during no load conditions.
3. Domestic hot water is preheated in a one pass system by a heat exchanger in the storage tank and then flows into a standard domestic hot water tank.
4. Auxiliary energy is provided by a forced air furnace for space heating and the standard hot water tank for the hot water requirements.

Building demand versus solar energy supplied for the single-family heating system is as shown in Figure 2.2-3. Pertinent comments are:

1. Solar energy supplied to home space heating and DHW load is lowest in Dec. as expected.
2. Maximum utilization of solar energy occurred in April and May.
3. System performance follows the supply of solar energy.

PLUMBING		AIR CONDITIONING	
Air eliminator		Condenser, Air cooled, Finned, Forced Air	
Expansion joint		Condenser, Air cooled, Finned, Static	
Heat exchanger		Condenser, Water cooled, Shell & Coil	
Pump		Condenser, Water cooled, Shell & Tube	
Strainer		Dryer	
Tank		Filter line	
Thermometer		Filter & strainer	
Thermostat		Fusible plug	
Valve		High side float	
Check		Motor compressor, sealed crank case reciprocating	
Mixing		Motor compressor, sealed crank case rotary	
Gate (manual)		Orifice	
Globe (manual)		Pressure switch	
Float		Rupture Disc	
Lock Shield (or equiv)		Sight Glass	
Motor operated		Strainer	
Reducing Pressure		Thermal bulb	
Solenoid operated		Thermostat remote bulb	
Angle		Vibration eliminator	
3 way		Pipe Cap	
4 way		Cross	
Relief valve		Elbow 45°	
Vent Point		Elbow	
Compressor		Joint	
Valve		Plug	
Angle check		Reducer	
		Sleeve	
		Tea	
		Union	

Figure 2.2-1. Standard Symbols used on System Schematics
(From S30014)



NOTES:

1 INTERPRETATION OF DWG TERMS
AND SYMBOLS PER S30014.

Figure 2.2-2. System Schematic, Heating Single Family System

Table 2.2-1. Single Family System Description

MAJOR SOLAR HARDWARE

SOLAR COLLECTOR AREA: 192 FT² (13 TC - 100 PANELS)

THERMAL ENERGY STORAGE: 192 GAL. OF WATER

HX-1 CAPACITY: 40,000 BTU/HR
 COLLECTOR SIDE FLOW RATE 2.9 GPM
 WITH 30°F TEMPERATURE DROP
 TES SIDE FLOW RATE 9.0 GPM
 WITH 9°F TEMPERATURE RISE

HYDRONIC COIL CAPACITY: 30,000 BTU/HR
 TES SIDE FLOW RATE 9.0 GPM WITH
 7°F TEMPERATURE DROP
 AIR SIDE: 23°F TEMPERATURE RISE AT 1200 CFM

ANNUAL PERFORMANCE

PERFORMANCE PARAMETER	MADISON '68	WASH. D.C. '64
HEATING LOAD, MMBTU	84.8	58.3
HEATING ENERGY SUPPLIED, MMBTU	18.8	24.2
% OF LOAD	22.2	41.5
DHW LOAD, MMBTU	20.3	20.3
DHW ENERGY SUPPLIED, MMBTU	9.7	11.0
% OF LOAD	48.0	54.0
TOTAL LOAD, MMBTU	105.1	78.6
TOTAL ENERGY SUPPLIED, MMBTU	28.5	35.2
% OF LOAD	27.1	44.8
PARASITIC ENERGY REQUIRED, MMBTU	1.6	1.6
% OF TOTAL SOLAR ENERGY SUPPLIED	5.6	4.5

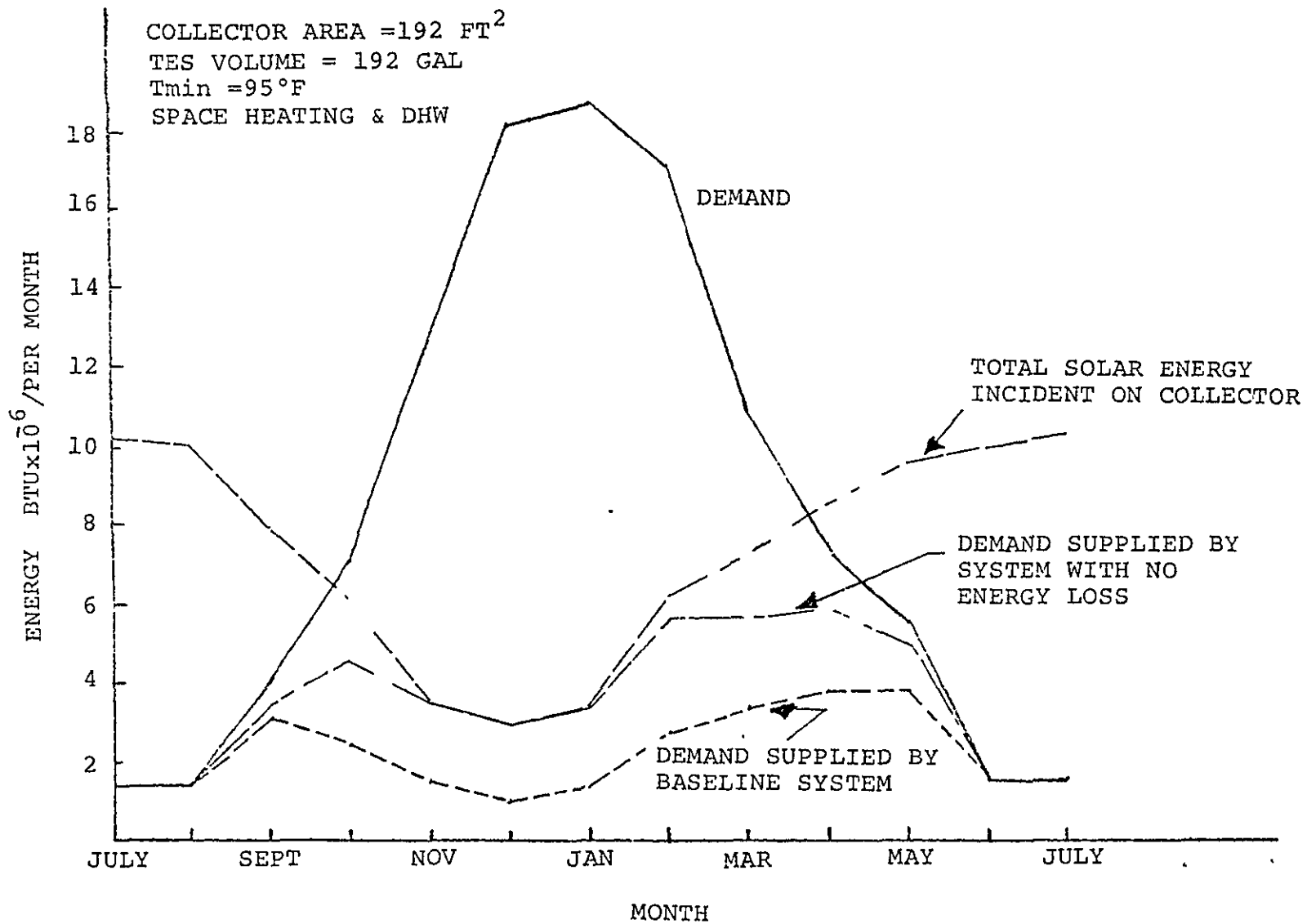


Figure 2.2-3. Supply/Demand Profile (Heating Single-Family' Madison '68 Weather)

4. Comparison to ideal system with no losses but finite storage capacity demonstrates limitations posed by collector efficiency and parasitics.
5. Comparison of ideal system to available insolation shows that all of the energy incident on the collector in Nov., Dec., and Jan. could be used by the home. Increasing storage capacity would not produce more delivered energy in that time period.

2.2.1.2 Multi-Family Heating Baseline System Configuration

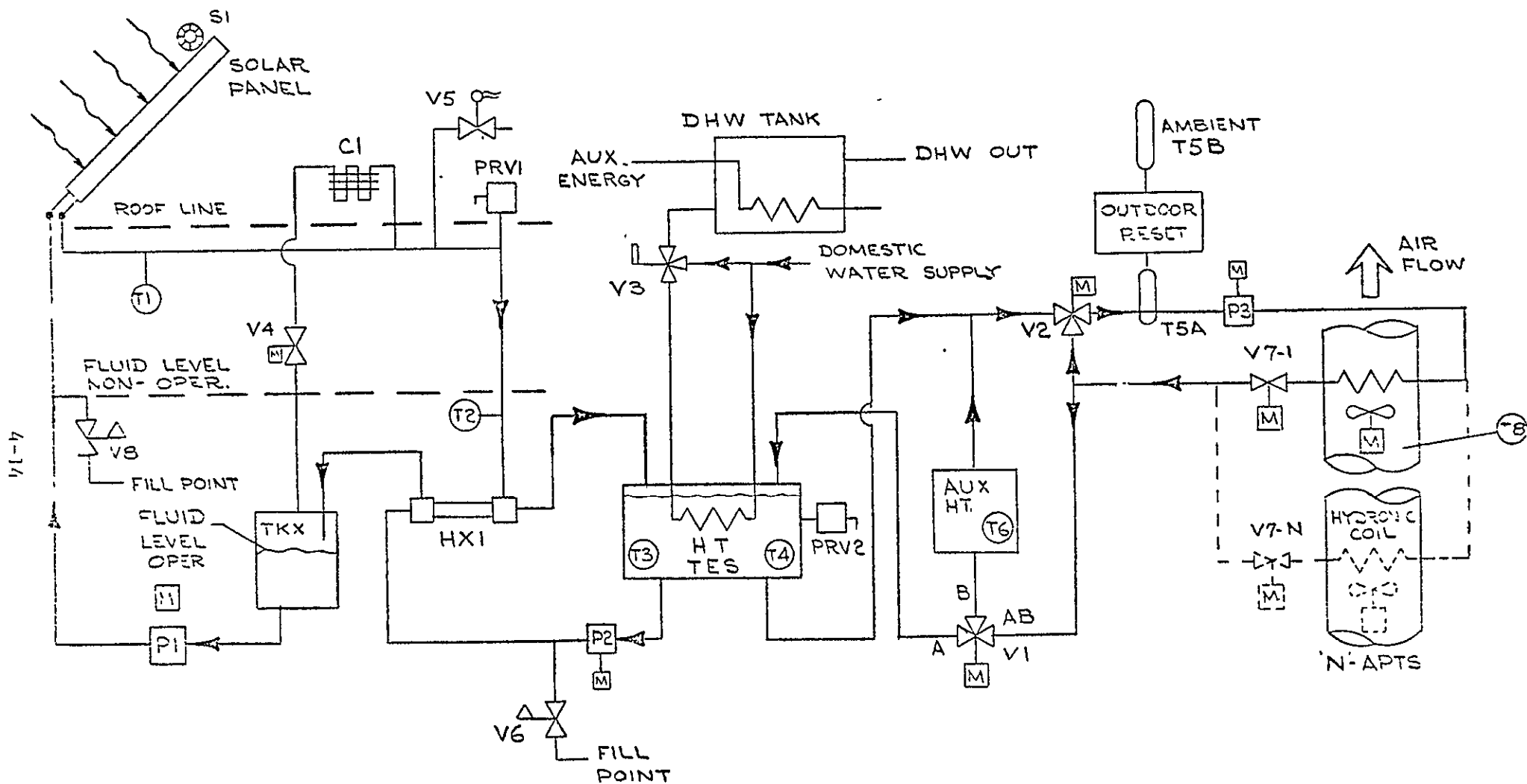
The baseline configuration for the multi-family heating system is shown in schematic form as Figure 2.2-4. Hardware and performance details for this system are summarized in Table 2.2-2. The primary features of this system are as follows:

1. Solar energy for space heating provided by heated water circulated through a hydronic coil located in air handler delivering hot air heat to each dwelling unit. Modulating valve V2 maintains constant fluid temperature to dwelling.
2. All of the solar energy is transferred from the solar collector loop to a central thermal energy storage tank.
3. The constant temperature circulating loop draws energy either from the TES or from a central boiler.
4. Domestic hot water is preheated in a one pass system by a heat exchanger in the storage tank and then flows into a standard domestic hot water tank.
5. Auxiliary energy is provided by the standard hot water boiler and a standard hot water tank.

Building demand versus solar energy supplied for the Multi-Family Heating System is as shown in Figure 2.2-5. Pertinent comments are.

1. Load and energy supplied profile similar to HSF system.
2. Most of load is DHW load.
3. Loss-less system uses all of solar energy available in Nov., Dec., and Jan. with the result that additional storage cannot improve performance in that time period for the real system.

ORIGINAL PAGE IS
OF POOR QUALITY



NOTES:

1 INTERPRETATION OF DWG TERMS
AND SYMBOLS PER. 630014.

Figure 2.2-4. System Schematic, Heating Multi-Family System

Table 2.2-2. Multi-Family System Description

MAJOR SOLAR HARDWARE

SOLAR COLLECTOR AREA: 896 FT² (60 TC-100 COLLECTORS)

THERMAL ENERGY STORAGE: 896 GAL. OF WATER

HX-1 CAPACITY: 170,000 BTU/HR
COLLECTOR SLIDE FLOW RATE 13.4 GPM
WITH 29°F TEMPERATURE DROP
TES SIDE FLOW RATE 26.9 GPM
WITH 13°F TEMPERATURE RISE

HYDRONIC COIL CAPACITY: 30,000 BTU/HR CAPACITY (12 UNITS)
(HYDRONIC COIL PROVIDES PEAK LOAD CAPABILITY)

ANNUAL PERFORMANCE

PERFORMANCE PARAMETER	MADISON '68	WASH. D.C. '64
HEATING LOAD, MMBTU	469.6	296.9
HEATING ENERGY SUPPLIED, MMBTU	30.5	50.8
% OF LOAD	6.5	17.1
DHW LOAD, MMBTU	165.6	165.6
DHW ENERGY SUPPLIED, MMBTU	118.6	133.0
% OF LOAD	71.6	80.3
TOTAL LOAD, MMBTU	635.2	462.5
TOTAL ENERGY SUPPLIED	149.1	183.8
% OF TOTAL	23.5	39.7
PARASITIC ENERGY REQUIRED, MMBTU	10.1	10.2
% OF TOTAL SOLAR ENERGY SUPPLIED	6.8	5.5

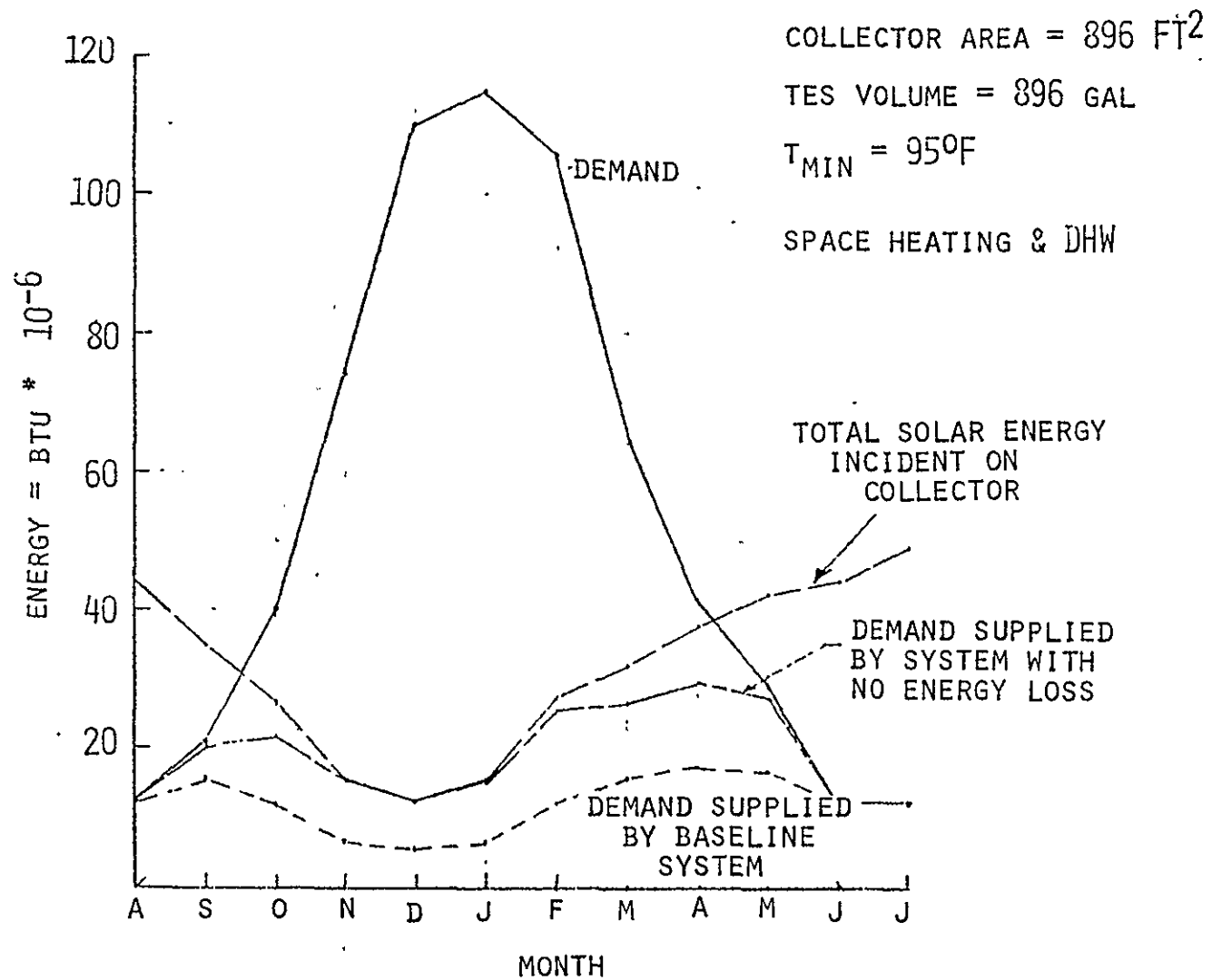


Figure 2.2-5. Supply/Demand Profile (Heating Multi-Family; Madison '68 Weather)

2.2.1.3 Commercial Heating Baseline System Configuration

The baseline configuration for the commercial heating system is shown in schematic form as Figure 2.2-6. Hardware and performance details for this system are summarized in Table 2.2-3. The primary features of this system are as follows:

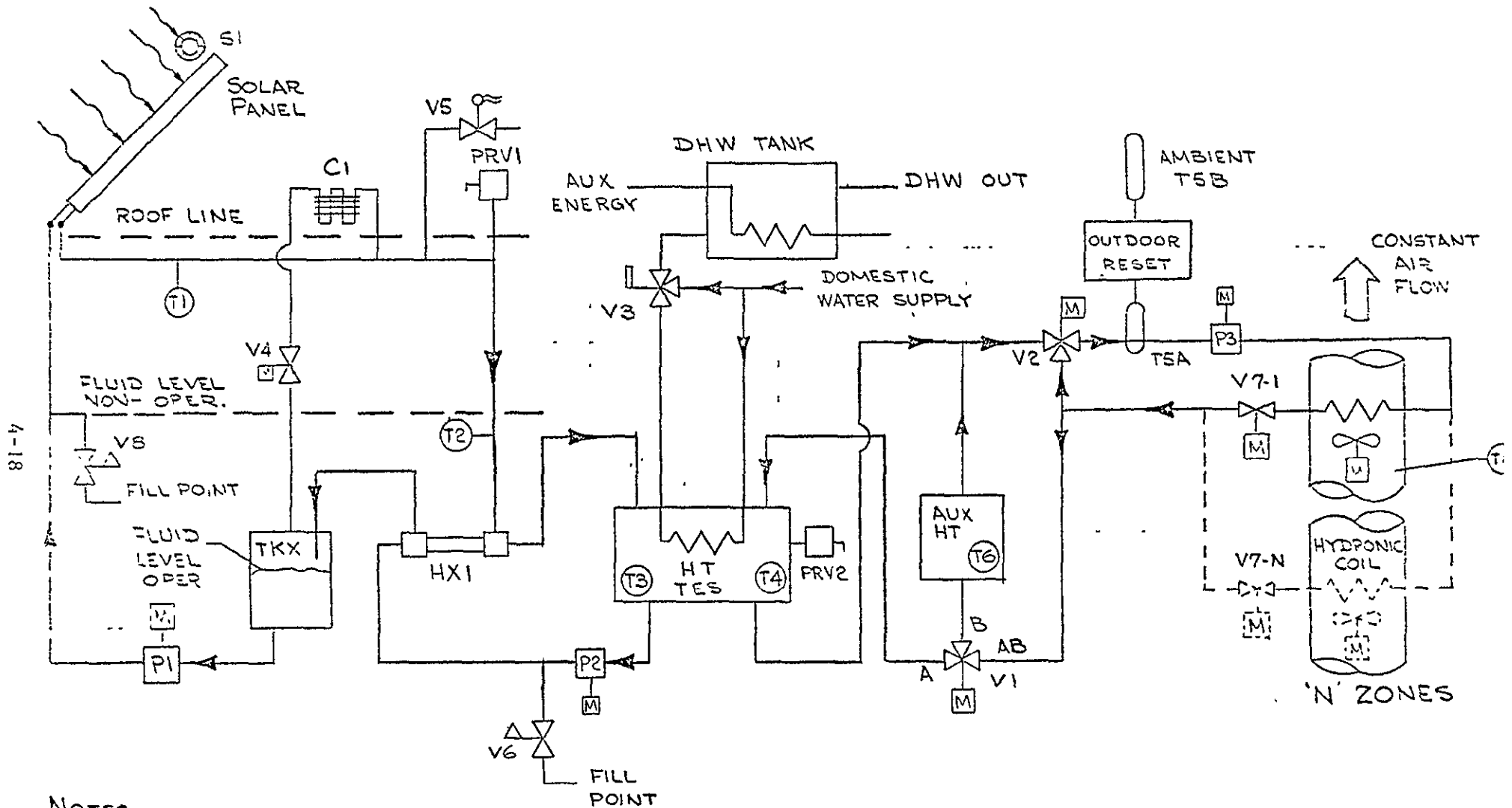
1. System is identical to multi-family residence system in concept and hardware types.
2. Individual building zones will have an air handler with a hydronic coil installed for heating just as for individual apartments in the multi-family system.

Building demand versus solar energy supplied for the Commercial Heating System is as shown in Figure 2.2-7. Pertinent comments are:

1. System performance follows solar energy availability.
2. Loss-less system uses all of solar energy available in January and February. Additional storage would not improve the performance of the real system in that time period.
3. Peak solar energy supply occurs in April and May.

2.2.1.4 Baseline System Summary

A summary of the major solar hardware required by the baseline heating system is presented in Table 2.2-4.



NOTES

1 INTERPRETATION OF DWG TERMS
AND SYMBOLS PER S30014.

Figure 2.2-6. System Schematic, Heating Commercial System

Table 2.2-3. Commercial System Description

MAJOR SOLAR HARDWARE

SOLAR COLLECTOR AREA: 2992 FT² (202 TC-100 PANELS)

THERMAL ENERGY STORAGE: 2992 GAL. OF WATER

HX-1 CAPACITY: 570 KBTU/HR
 COLLECTOR SIDE: FLOW RATE = 45 GPM
 WITH 29°F TEMPERATURE DROP
 TES SIDE: FLOW RATE = 90 GPM
 WITH 13°F TEMPERATURE RISE

HYDRONIC COIL CAPACITY: 1500 KBTU/HR FOR N ZONES
 1500/N KBTU/HR
 (HYDRONIC COIL TO PROVIDE PEAK LOAD)

ANNUAL PERFORMANCE

PERFORMANCE PARAMETER	MADISON '68	WASH. D.C. '64
HEATING LOAD, MMBTU	2028.1	1373.1
HEATING ENERGY SUPPLIED, MMBTU	369.1	439.4
% OF LOAD	18.2	32.0
DHW LOAD, MMBTU	55.3	55.3
DHW ENERGY SUPPLIED, MMBTU	49.1	50.3
% OF LOAD	88.7	91.0
TOTAL LOAD, MMBTU	2083.4	1428.4
TOTAL ENERGY SUPPLIED	418.2	489.7
% OF LOAD	20.0	34.3
PARASITIC ENERGY REQUIRED, MMBTU	27.1	26.7
% OF TOTAL SOLAR ENERGY SUPPLIED	6.5	5.5

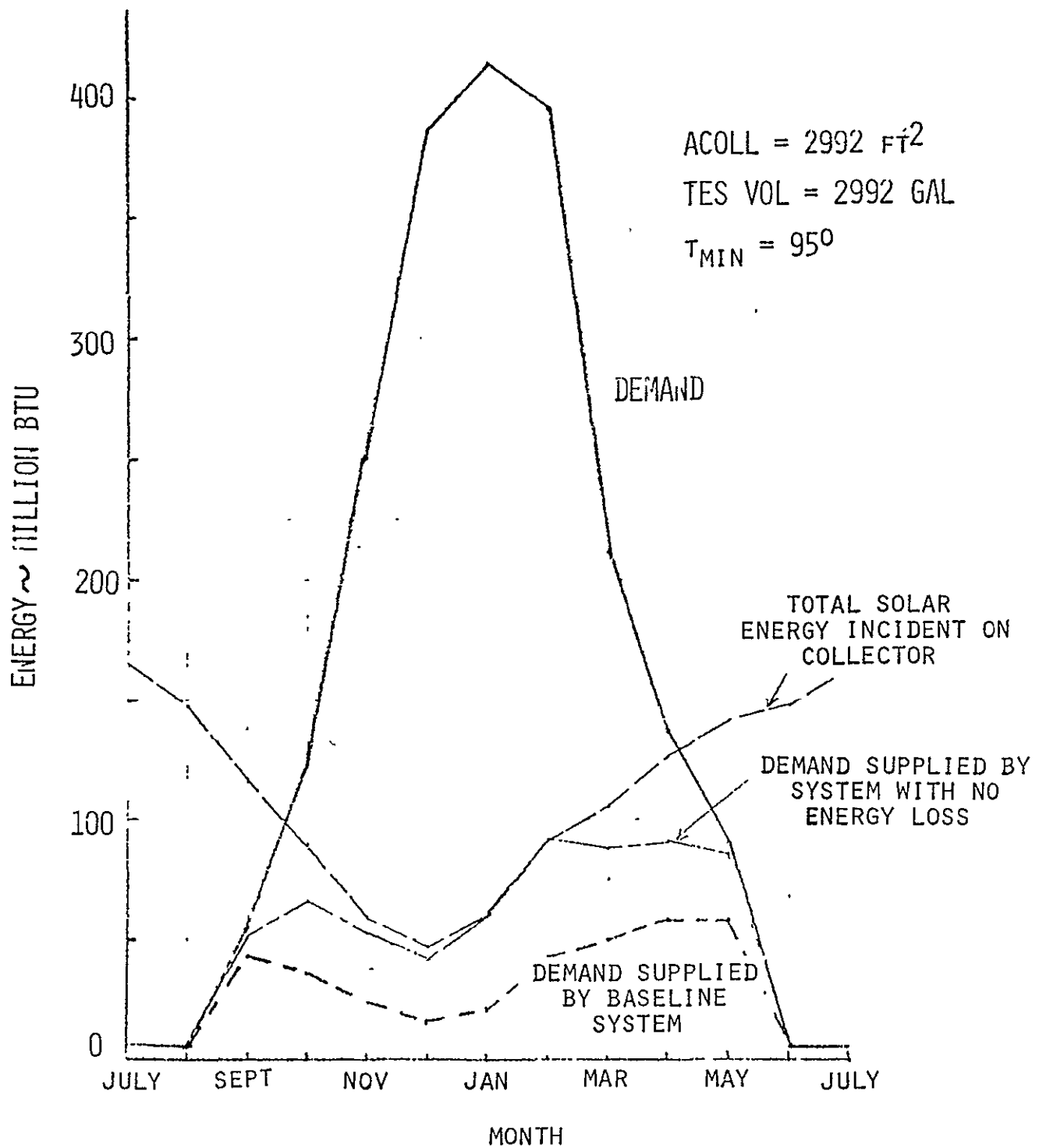


Figure 2.2-7. Supply/Demand Profile
 (Heating Commercial; Madison '68 Weather)

Table 2.2-4. Prototype System Summary
Heating Only Systems

	HSF	HMF	HCOM
<u>SOLAR COLLECTOR LOOP</u>			
SOLAR COLLECTOR AREA (FT ²)	192	896	2992
EXP/DRAIN DOWN TANK (GAL)	20	50	300
PUMP CAPACITY (GPM)	3	14	45
PUMP HEAD (FT)	62	72	63
<u>ENERGY TRANSPORT LOOP</u>			
THERMAL ENERGY STORAGE (GAL)	192	896	2992
NO. OF PUMPS	1	2	2
PUMP CAPACITY (GPM)	9	2@ 27	2@ 90
PUMP HEAD (FT)	40	1@ 17	1@ 17
		1@ 72	1@ 105
HEAT EXCHANGER, (HX-1) CAPACITY (KBTU/HR)	40	170	600
<u>AIR HANDLERS</u>			
QUANTITY	1	12	N
HEATING CAPACITY (KBTU/HR)	45	30	1500/N
HYDRONIC COIL CAPACITY (KBTU/HR)	30	30	1500/N
<u>AUXILIARY HEAT</u>			
HEATING CAPACITY (KBTU/HR)	45	300	1500
DHW CAPACITY (KBTU/HR)	35	420	55
<u>DOMESTIC HOT WATER</u>			
HOT WATER (QTY)	1	1	1
HOT WATER (GAL)	82	720	200

ORIGINAL PAGE IS
OF POOR QUALITY

9/29/76

2.2.1.5 Trade Studies

A series of trade studies were performed to assess the effect on the total solar energy delivered by the following:

1. System Configuration Class
2. TES Temperature
3. TES Volume
4. Heat Exchanger HX-1 Size
5. Domestic Hot Water Heating Approach

2.2.1.5.1 System Configuration Class

Three classes of configurations were analyzed. Simplified schematics for configurations 1, 2, and 5 are presented in Figures 2.2-8, 2.2-9, and 2.2-10, respectively. Configuration 1 provides for direct solar heating. Configuration 2 requires that all solar energy be delivered to the TES first and results in a simplified system. Configuration 5 is introduced to evaluate the penalty associated with adding auxiliary energy directly to the TES. Configurations 3 and 4 include heat pumps and will be used for heating and cooling analysis.

The results of the studies are typified by the performance comparisons for the multi-family dwelling in Washington, D.C. as presented in Figure 2.2-11. The significant conclusion is that there is little to choose between configurations 1 or 2 and both are better performers than configuration 5.

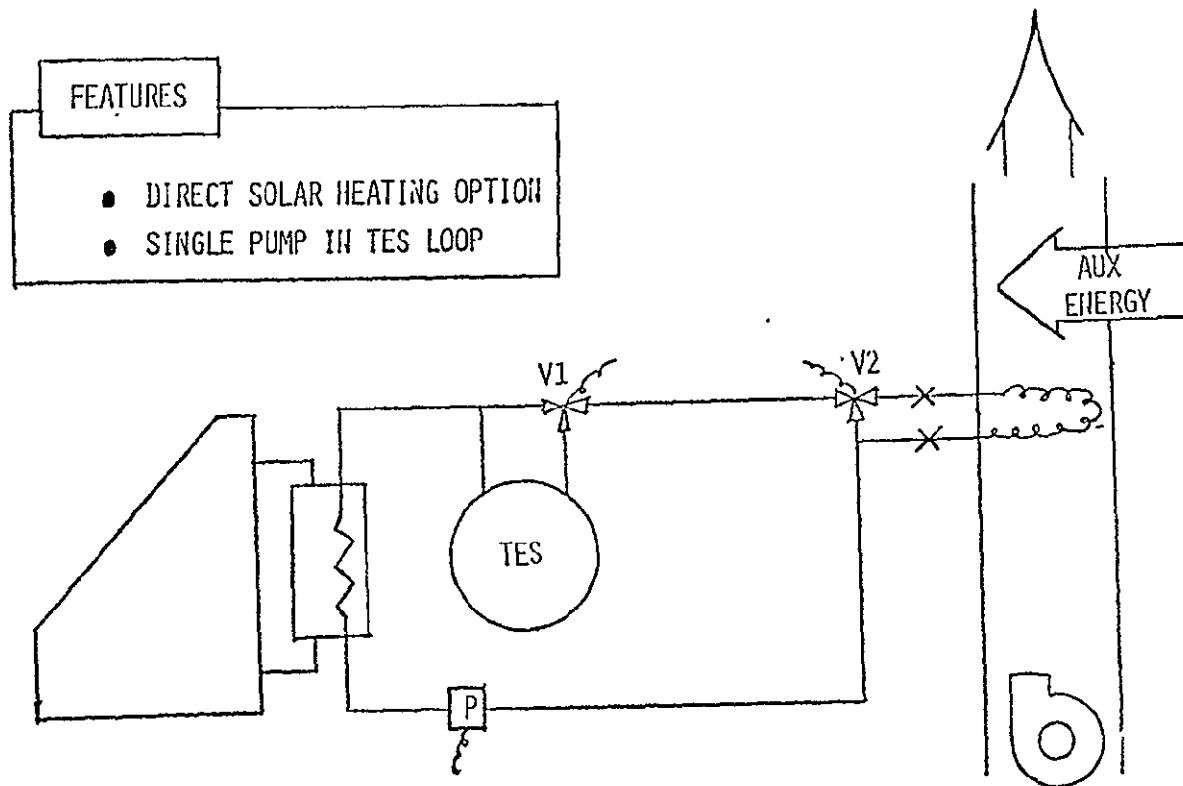


Figure 2.2-8. System Configuration No. 1

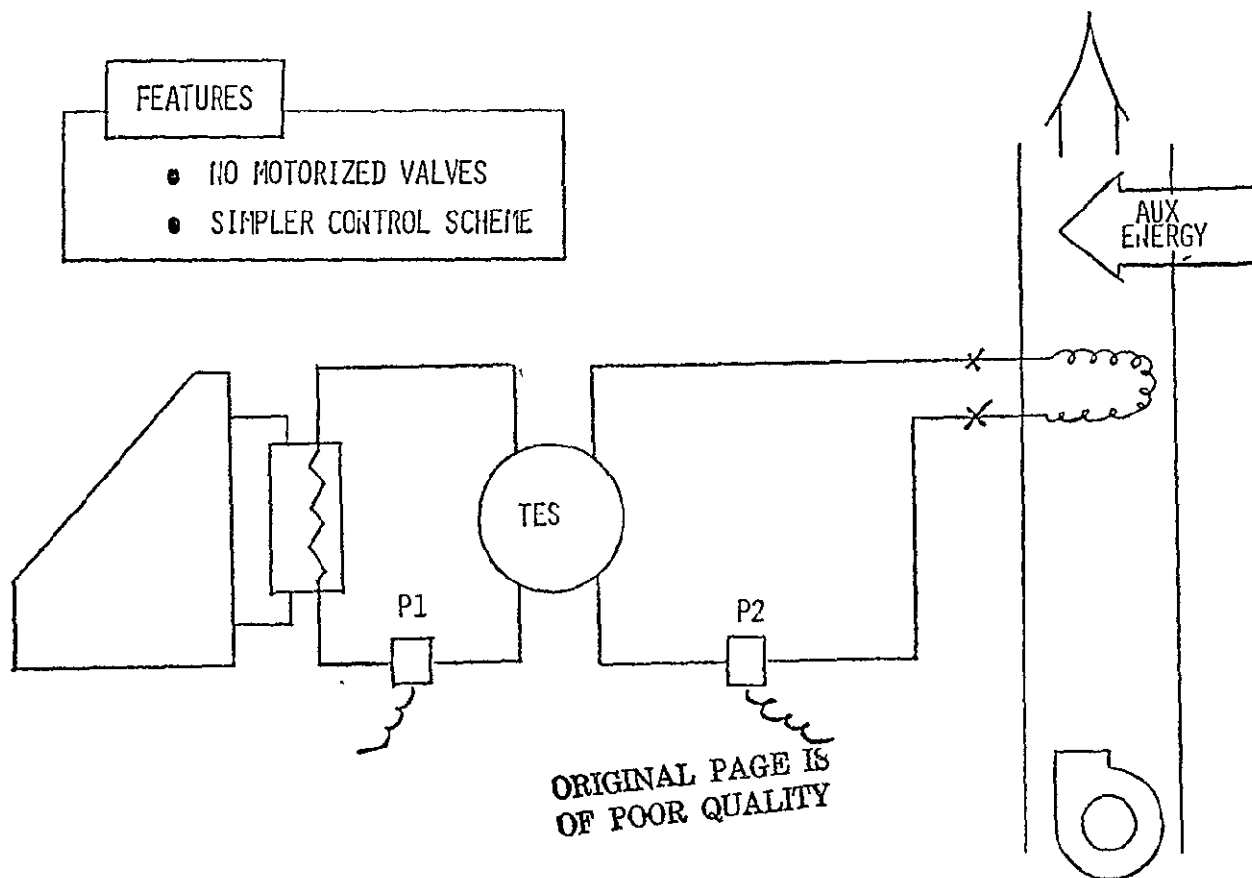


Figure 2.2-9. System Configuration No. 2

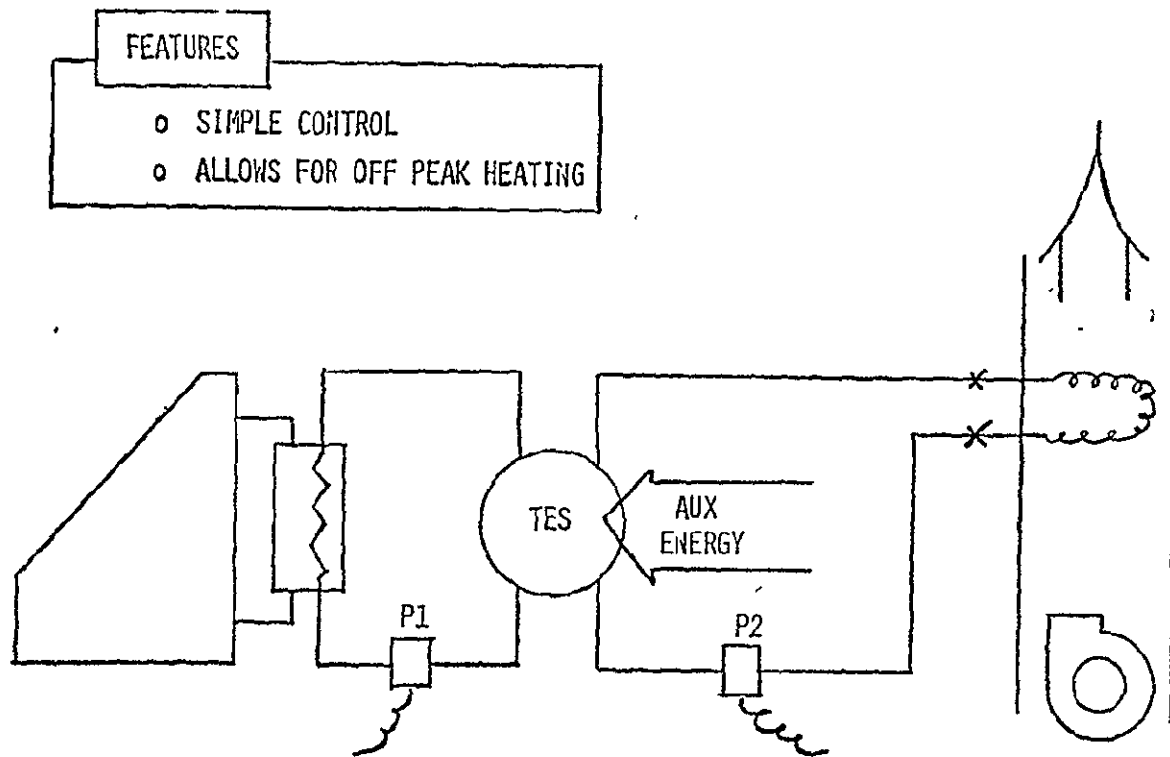


Figure 2.2-10. System Configuration No. 5

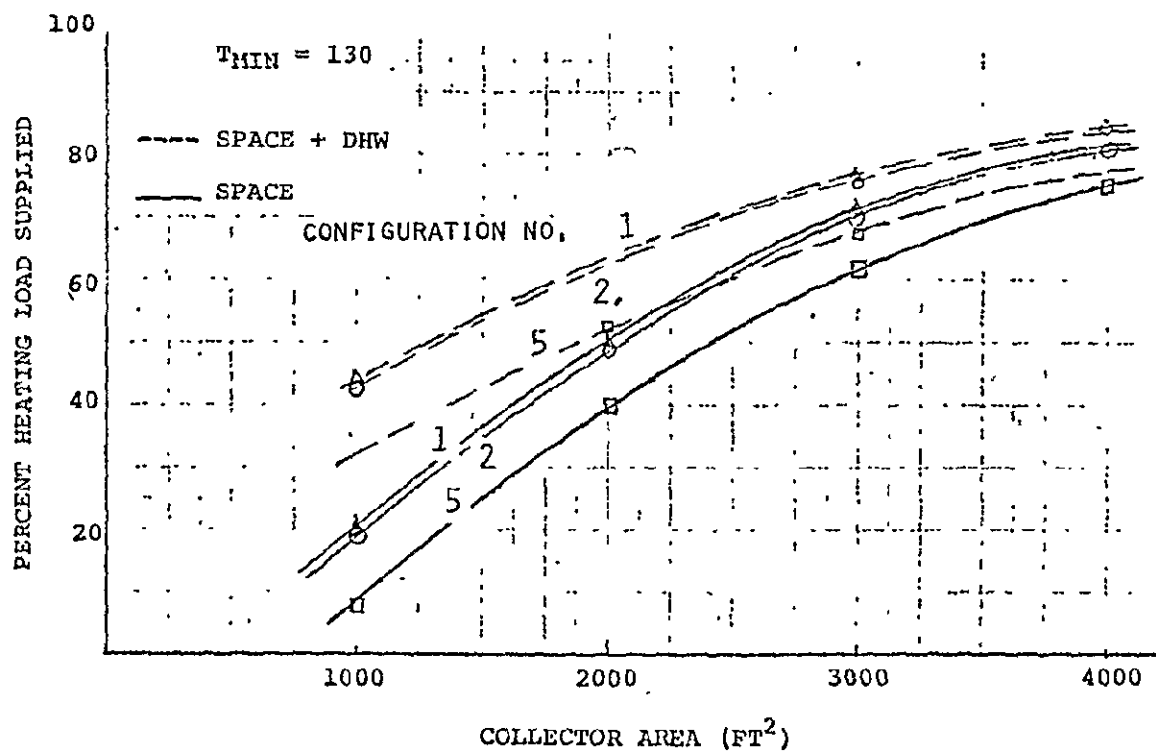


Figure 2.2-11. Effect of Configuration - Multi-Family Residence

2.2.1.5.2 TES Temperature

A study was made of the energy delivered as a function of the minimum TES temperature used for space heating. In Madison a 95°F minimum temperature was compared to a 130°F minimum temperature with the results shown in Figure 2.2-12. The conclusion is that the lower the temperature, the better. The 95°F value was selected as a lower bound since according to design practice, an 85°F air discharge temperature is considered minimal for comfort leaving a 10° temperature differential between the minimum liquid into minimum air out of the hydronic coil.

2.2.1.5.3 Storage Volume

The influence of TES storage volume was evaluated by a number of system simulations using fixed collector areas and fixed storage volumes. The results can be normalized by comparing energy delivered to the gallons of storage per square foot of collector area. One case is presented in Figure 2.2-13. The study led to the conclusion that increasing the specific capacity beyond 1.0 gal/ft² of collector does not significantly increase the annual energy delivered. Below 1.0 gal/ft² of collector there is a noticeable decrease in the annual energy collected.

2.2.1.5.4 Heat Exchanger, HX-1, Size

A study was made of the influence of the size of the solar loop heat exchanger, HX-1, on the solar energy delivered. The results are presented in Figure 2.2-14 and lead to the conclusion that over sizing this heat exchanger does nothing to improve the supply of solar energy to the load.

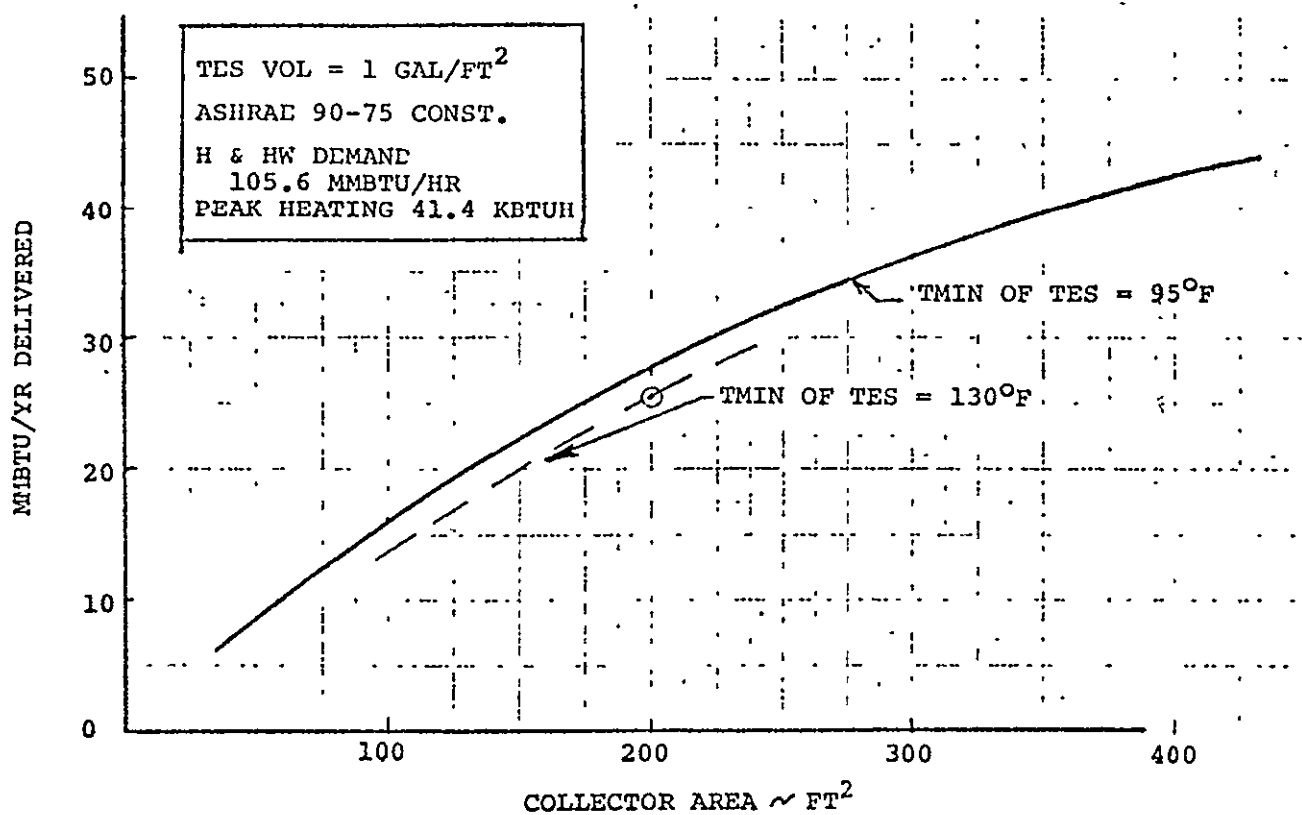


Figure 2.2-12. Effect of TES Temperature -
 Energy Delivered to SF Home, Madison

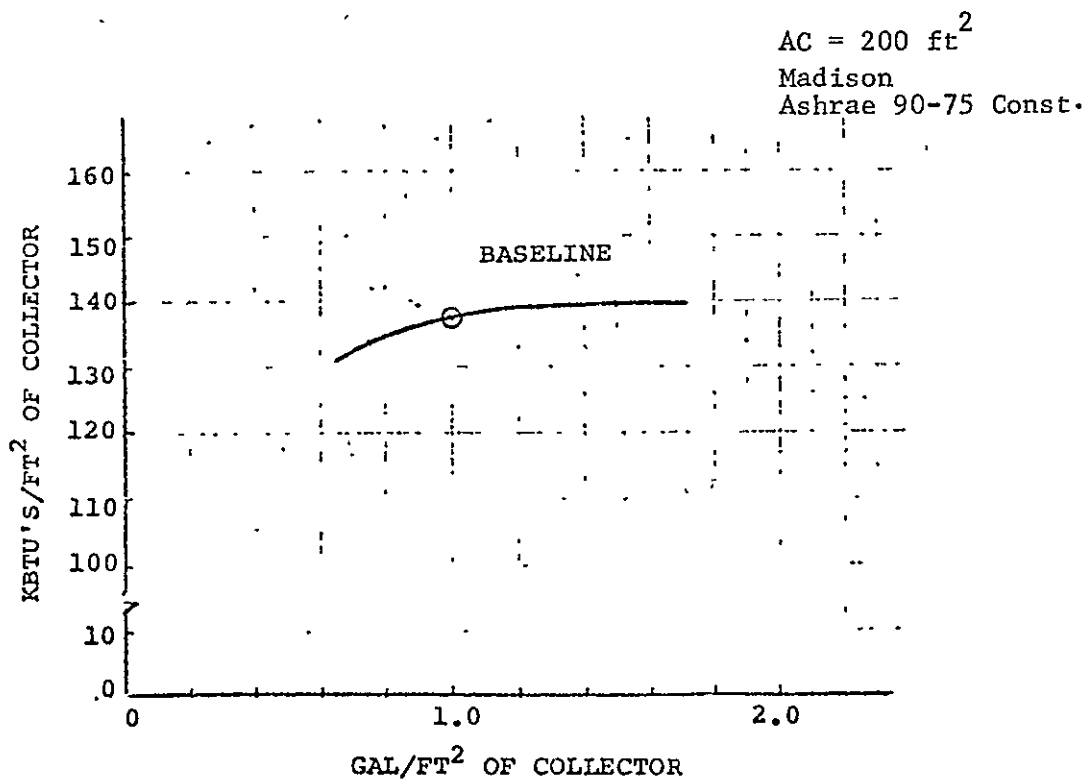


Figure 2.2-13. Effect of Storage Volume
 Single Family Residence

ORIGINAL PAGE IS
 OF POOR QUALITY

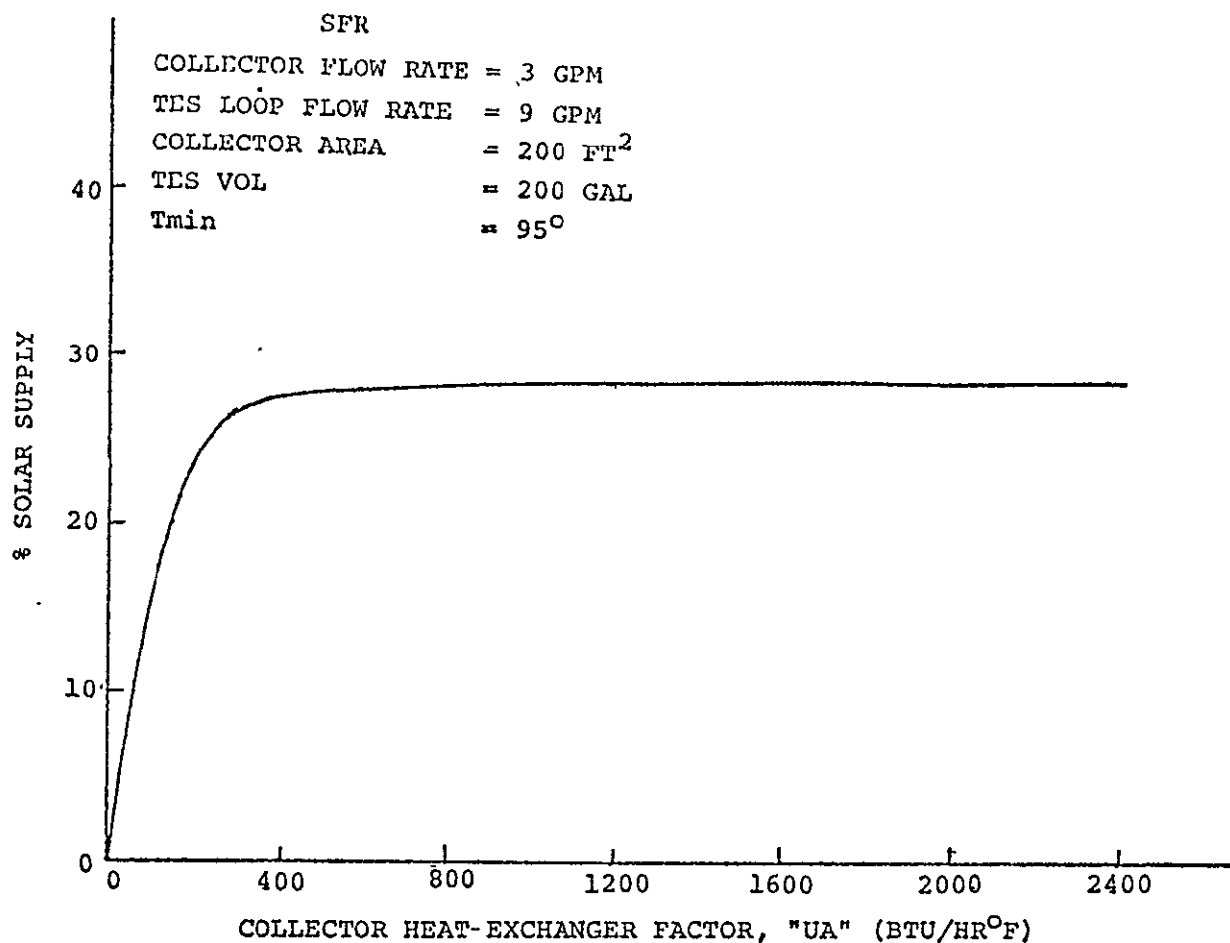


Figure 2.2-14. Influence of HX-1 Size
on System Performance

2.2.1.5.5 Domestic Hot Water Heating Approach

Two configurations for supply solar energy for domestic hot water were studied. One included a closed loop between the TES and a pre-heat tank with a circulatory pump. The other was a simple one pass through a heat exchanger located in the TES approach. The study was performed by investigating the influence of the heat exchanger size for both approaches. The results are contained in Figure 2.2-15. The recirculating approach provides a greater percentage of hot water as expected. Simpler one pass approach requires a larger heat exchanger and also provides less hot water. However, considering that the recirculating approach requires a pump, a pre-heat tank, and controls, and that the energy not used for DHW is available for space heating, it was decided to use the one pass approach for the baseline system.

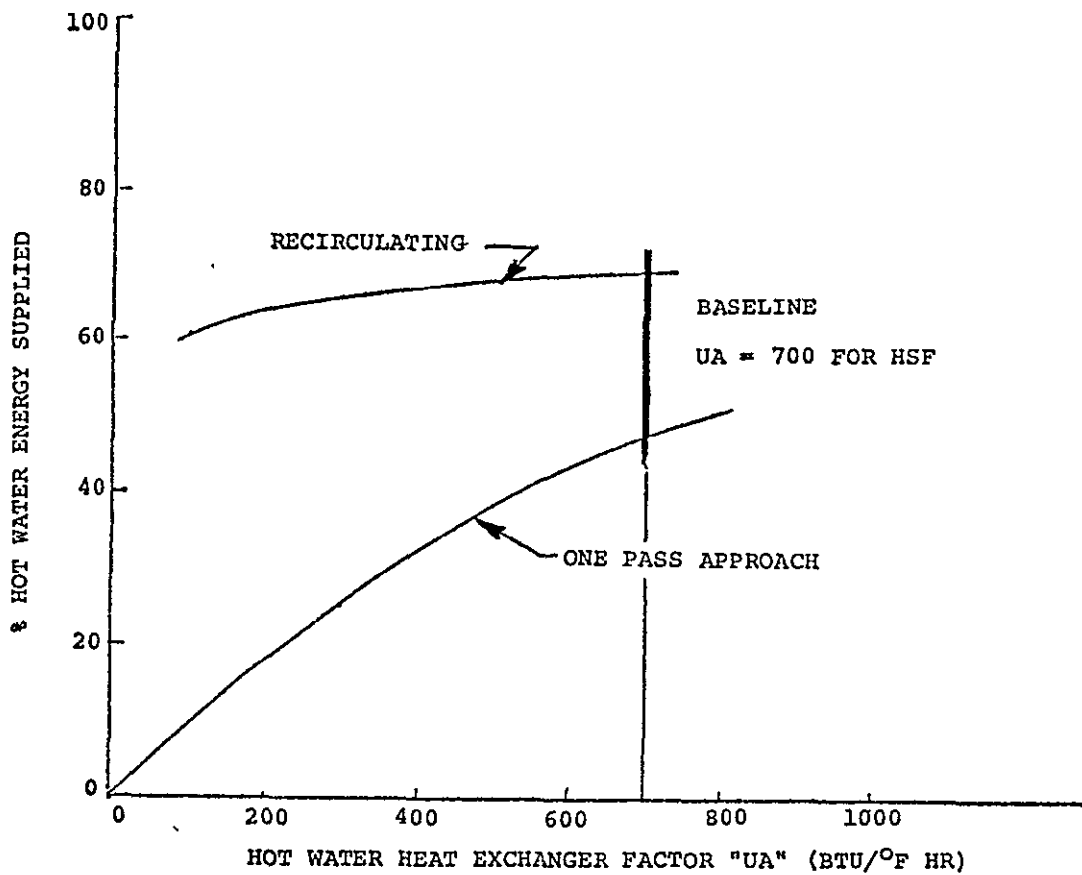


Figure 2.2-15. Recirculating vs One Pass Heat Exchange for DHW

ORIGINAL PAGE IS
OF POOR QUALITY

2.2.1.6 Economics

Economics was selected as the criteria for sizing systems. The owner/operator of a building has great interest in his cost to heat/cool the building and to provide hot water. The parameter selected as the most appropriate economics factor was the cost of energy (per MMBtu) delivered to the loads. This parameter can include the life cycles costs, discounted values of future costs/benefits, system life, payback period, and other economic factors. It also can be directly compared to the cost of conventional energy and can be converted to a total annual energy costs if desired.

The cost analysis consisted of estimating the installed cost of a solar heating system as a function of the collector area , the dominant cost parameter. The benefits would be the energy supplied by the system as a function of collector area. The ratio between cost and energy supplied provides an equivalent solar fuel cost that can be compared to costs for other types of energy.

Based on prior GE work on the National Solar Demonstration Program for NSF and ERDA, a tractable approach is to represent the cost for an installed solar heating system as the sum of a fixed cost plus a cost based on the number of collector panels as follows:

$$\text{Installed cost} = \alpha + B \times A_c$$

where α - a parameter dependent on building type and size

B - a parameter relatively independent of building
for heating only systems

A_c - Collector area

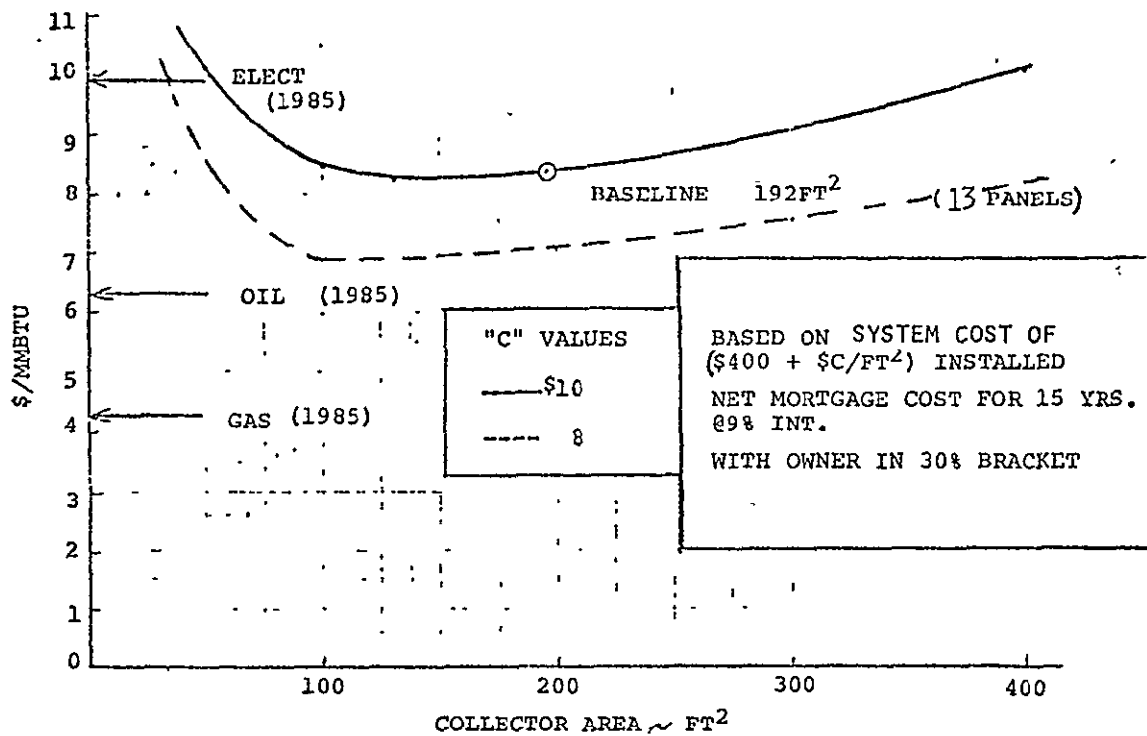


Figure 2.2-16 Cost of Solar Energy Delivered - Single Family Home, Madison, Wisc.

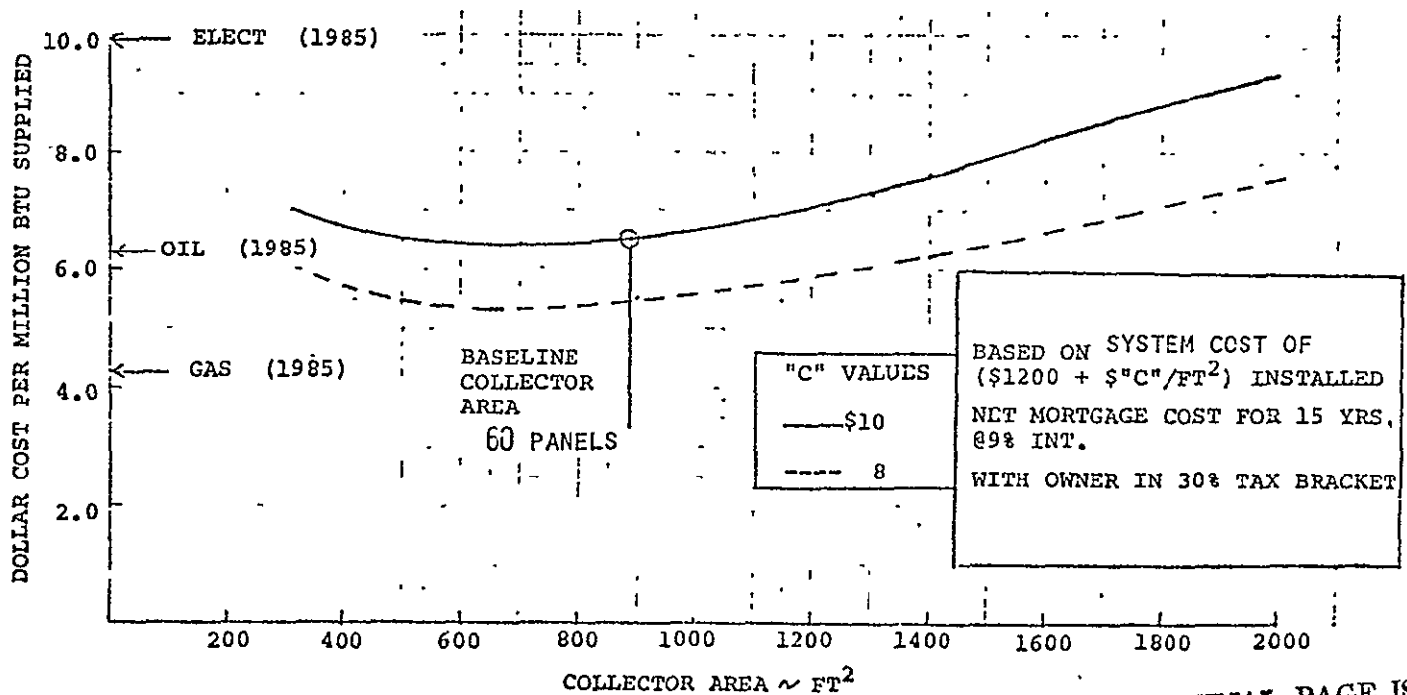


Figure 2.2-17 Multi-Family Residence, Cost of Solar Supplied Energy - Madison, Wisc. 1968

The following values were used for the pre-PDR analyses:

$$C_X = \$400 \text{ for HSF}$$

$$= \$1200 \text{ for HMF}$$

$$= \$2000 \text{ for HCOM}$$

$$B = \$8/\text{ft}^2 \text{ of collector and } \$10/\text{ft}^2 \text{ of collector}$$

Note that the value of B is compatible with a collector cost of $\$4.50/\text{ft}^2$

F.O.B. factory.

Two approaches for cost accounting were selected that are compatible with accepted practices. For both residential buildings, costs were reduced to the net after tax cost of the mortgage required to pay for the solar system over a 15 year period. A discounted cash flow (levelized costs) technique which takes into account return on investment was used for the commercial application.

The results of the study used to select the PDR baseline system sizes are presented in Figures 2.2-16 thru 2.2-18. Note that in each case there is a relatively broad span of collector areas for which the cost of solar energy does not significantly change. The sizing philosophy is to select the largest size solar system that provides energy at a lower cost than the auxiliary energy source. Where the solar energy cost was never lower than the auxiliary energy cost the solar system was sized to provide near minimum delivered energy costs. This would be size of the system that first becomes economically competitive.

More detailed economic analyses will be completed during the final design stages and will be used to evaluate components and design directions required to

minimize the solar heating systems costs and to establish cost goals.

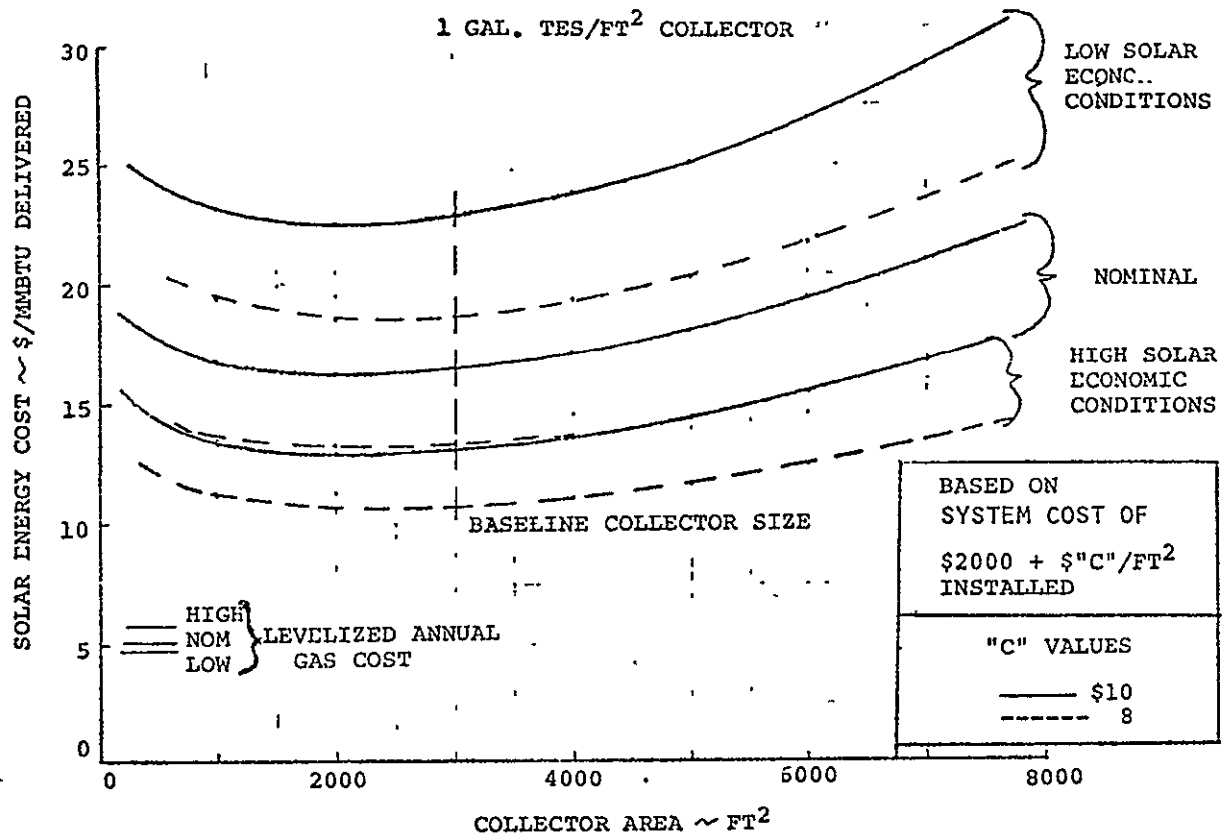


Figure 2.2-18 Cost of Solar Energy - Commercial Building, Madison, Wisc.

2.2.2 SYSTEMS ANALYSIS OF HEATING AND COOLING SYSTEMS

The starting point for heating and cooling systems analysis were the system configurations from the proposal. For reference, a functional block diagram from the proposal for the single family system is reprinted here as Figure 2.2-19. The system features a heat pump which can be driven either by a Low Temperature Rankine solar driven engine or by an electric motor. Application studies coupled with a survey of proven GE heat pump equipment designs resulted in the selection of the 3 Ton and 10 Ton sizes for development. Development of first cycle hardware items is underway.

The major effort in this reporting period centered on providing data for program decisions on the S/E DHP configurations. The activities included updating the concept analyses to refine the choice of the solar driven heat pump capacities, performing trade studies on heat pump configuration through the efforts of GE CR&D, and developing a detailed Low Temperature Rankine simulation code.

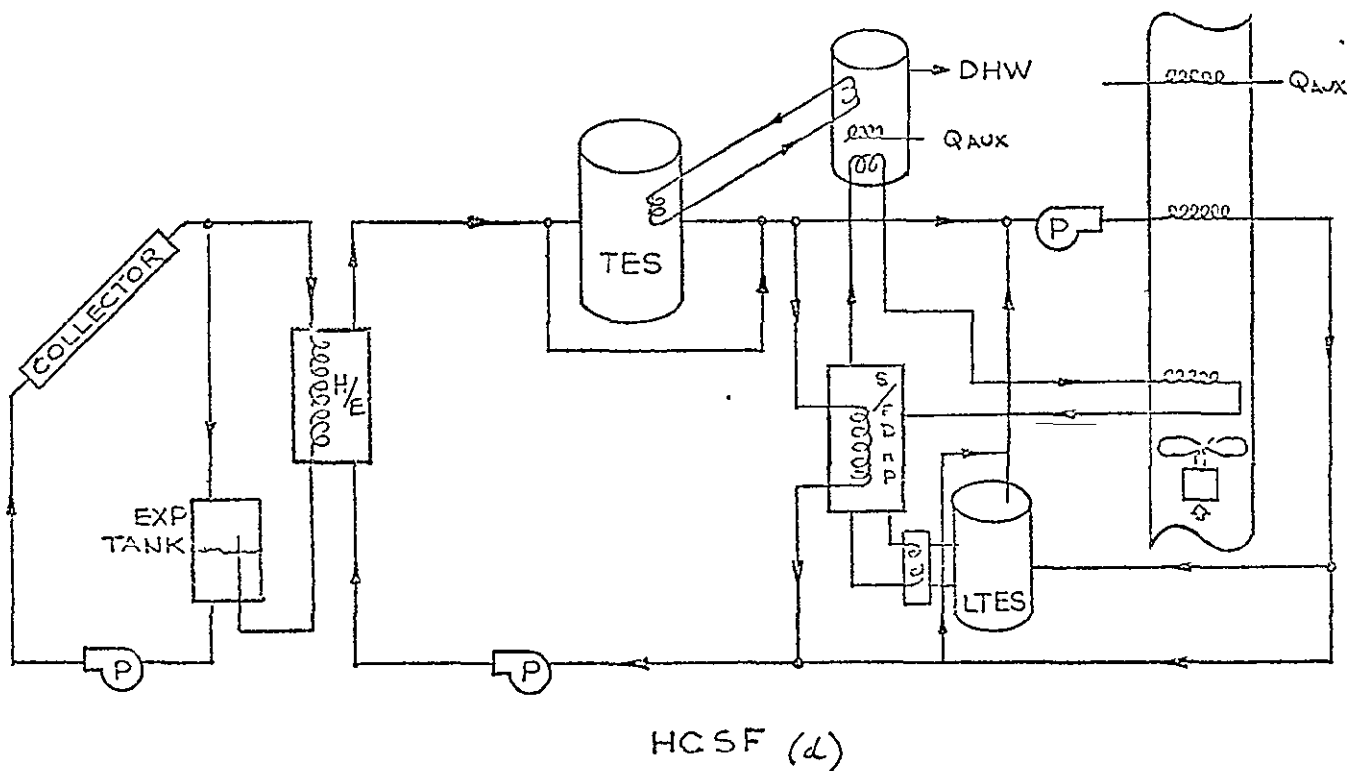


Figure 2.2-19. Functional Block Diagram for Single Family Heating & Cooling System

2.2.2.1 SDHP Analysis

A preliminary system analysis was performed to evaluate the influence of the R11 boiler outlet temperature and nominal capacity on the cooling energy delivered to a single family home having a 3 TON air conditioning load in Wash., D.C. Previous studies have established Washington, D.C. as a good site for heating and cooling studies because of climate and demographics. The studies included boiler outlet temperatures of 250°F and 300°F, collector areas of 288ft², 432ft², and 576ft², and heat pump capacities of 1, 1½, 2, 2½, 3, and 4 tons output. The fraction of the cooling demand supplied by the SDHP is shown in Figure 2.2-20. The seasonal performance factor based on solar energy input to the boiler was determined and the results are presented in Figure 2.2-21. The conclusion from this preliminary work is to size the solar driven section on a seasonal bases rather than on peak demands.

A re-evaluation of the use of solar driven equipment for heating was made on the basis that the system configuration will allow a direct solar heating mode. The result of this work is that the solar driven equipment will be used for cooling only. This eliminates one of the heat exchangers in the system and the complica-

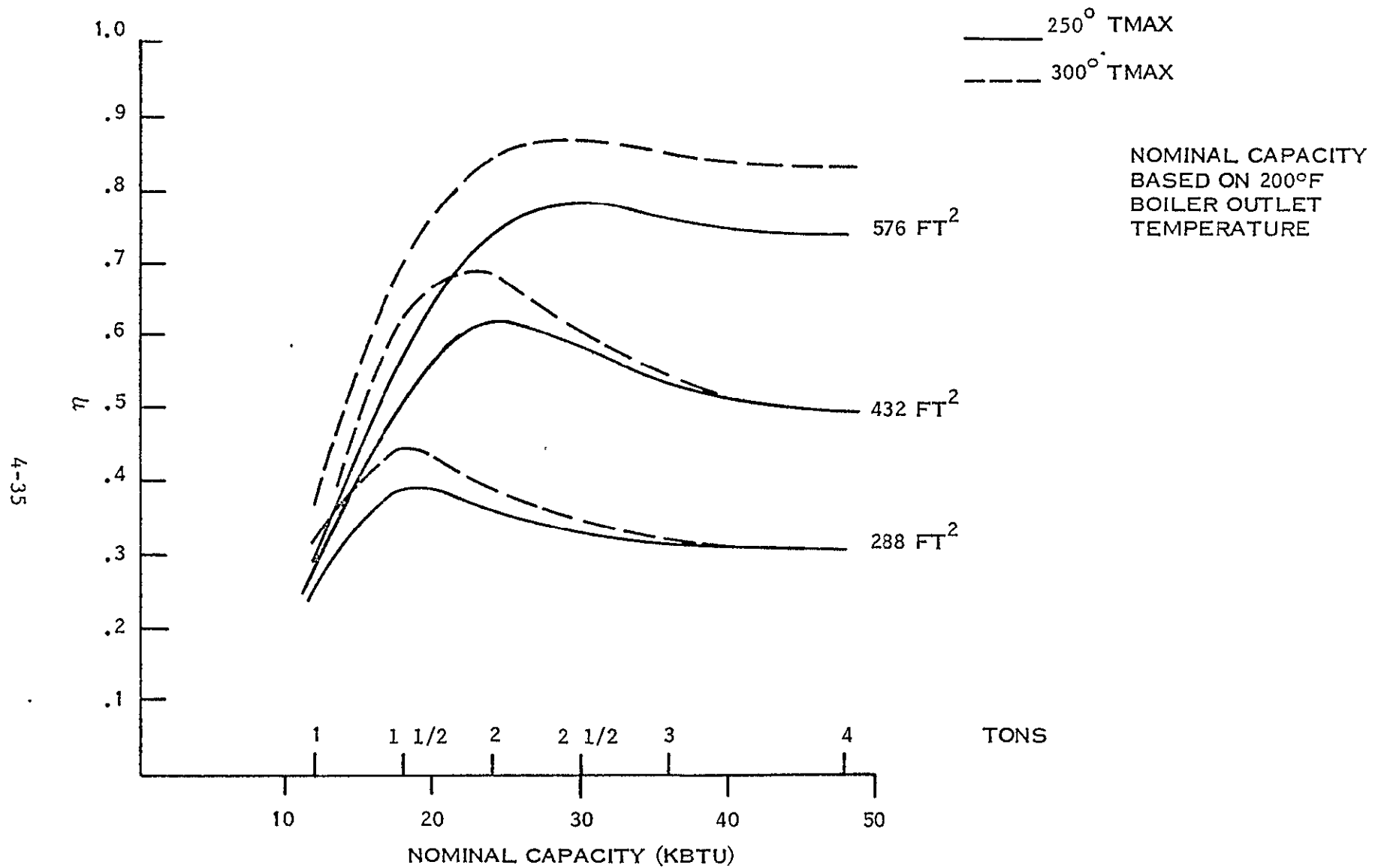


Figure 2.2-20. Fraction of Seasonal Cooling Load Supplied by the SDHP(N)

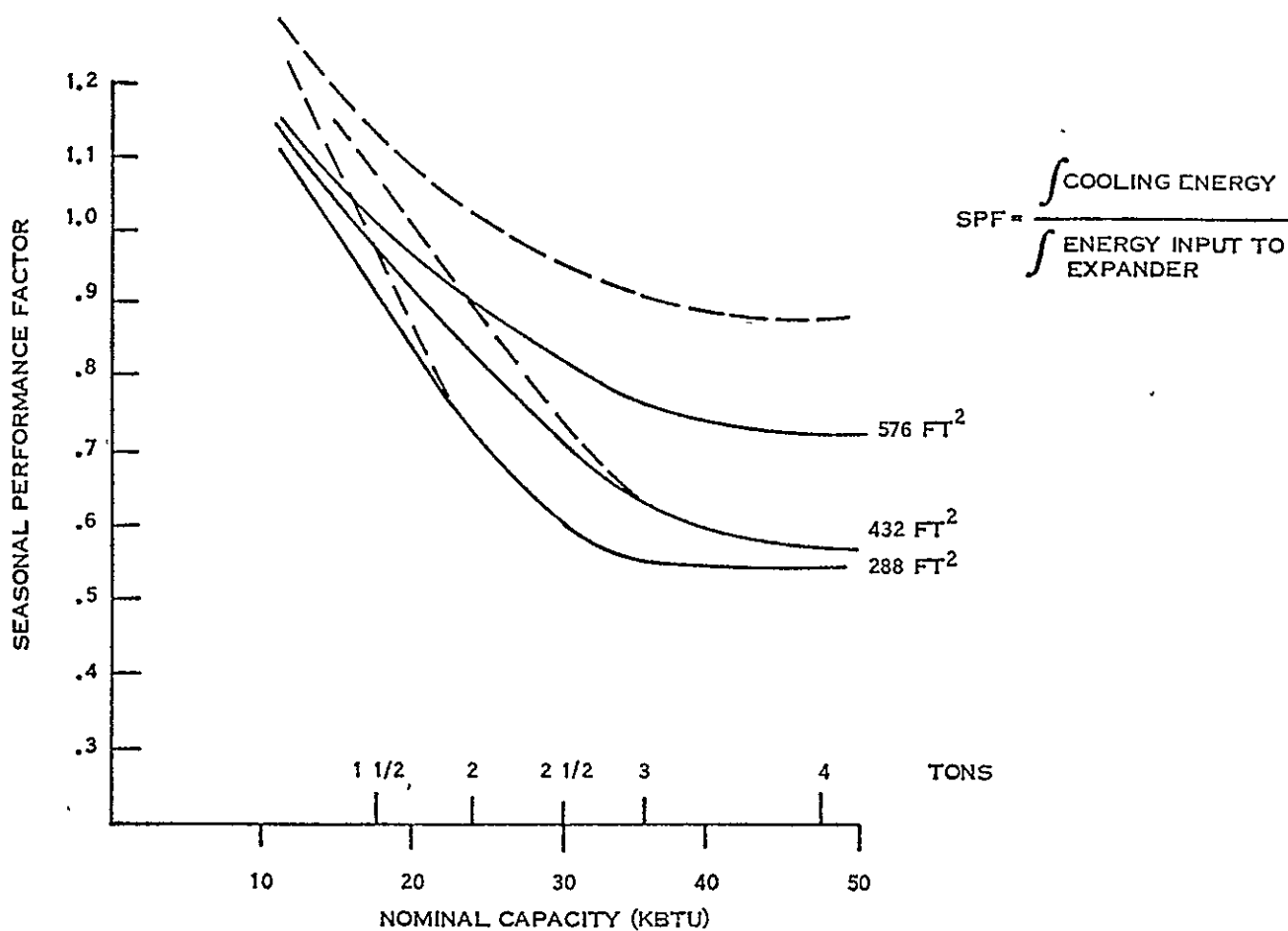
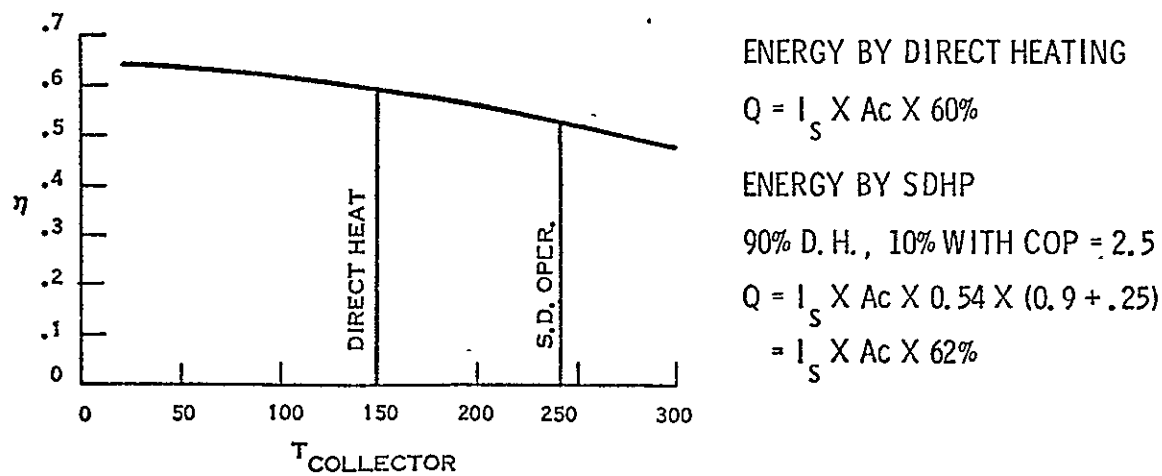


Figure 2.2-21 Solar Rankine A/C Seasonal Performance Factor



CONCLUSION

SDHP HAS THEORETICAL ADVANTAGE OF 2 PERCENTAGE POINTS ABOVE DIRECT HEATING WITHOUT CONSIDERING PARASITICS

Figure 2.2-22 Solar Rankine Heat Pump for Heating Mode

tions of winter operation. See Figure 2.2-22.

A re-evaluation was made of the domestic hot water heat exchanger in the LTR refrigerant loop. Two factors became important. The first is that the heat exchanger is useful only when the SDHP is working, and a preliminary system simulation showed this to occur principally between 10 A.M. and 3 P.M. The second is that the peak DHW demands occur earlier in the morning and later in the evening. On that basis the DHW heat exchanger in the refrigerant loop was eliminated from the current preferred system configuration. As more detailed studies are made, the benefits of this heat exchanger will become better defined and it could be re-instituted into the system if it is proven to provide a net benefit.

2.2.2.2 Heat Pump Configurations

The GE Corporate Research and Development Laboratory has analyzed a number of heat pump configurations to find the best match between the Rankine engine and the heat pump compressor. A program was defined to analyze a nominal 3 Ton and 10 Ton S/EDHP system using air to air, air to water, water to air, and water to water heat exchangers. During this reporting period only the 3 Ton air to air system analysis was initiated. Based on the previous work, a rating of $2\frac{1}{2}$ tons of solar driven cooling capacity (30KBTUH) is desired for the 3 Ton rated S/EDHP. Table 2.2-5 shows the sizes of equipment simulated.

2.2.2.3 LTR System Analysis Code

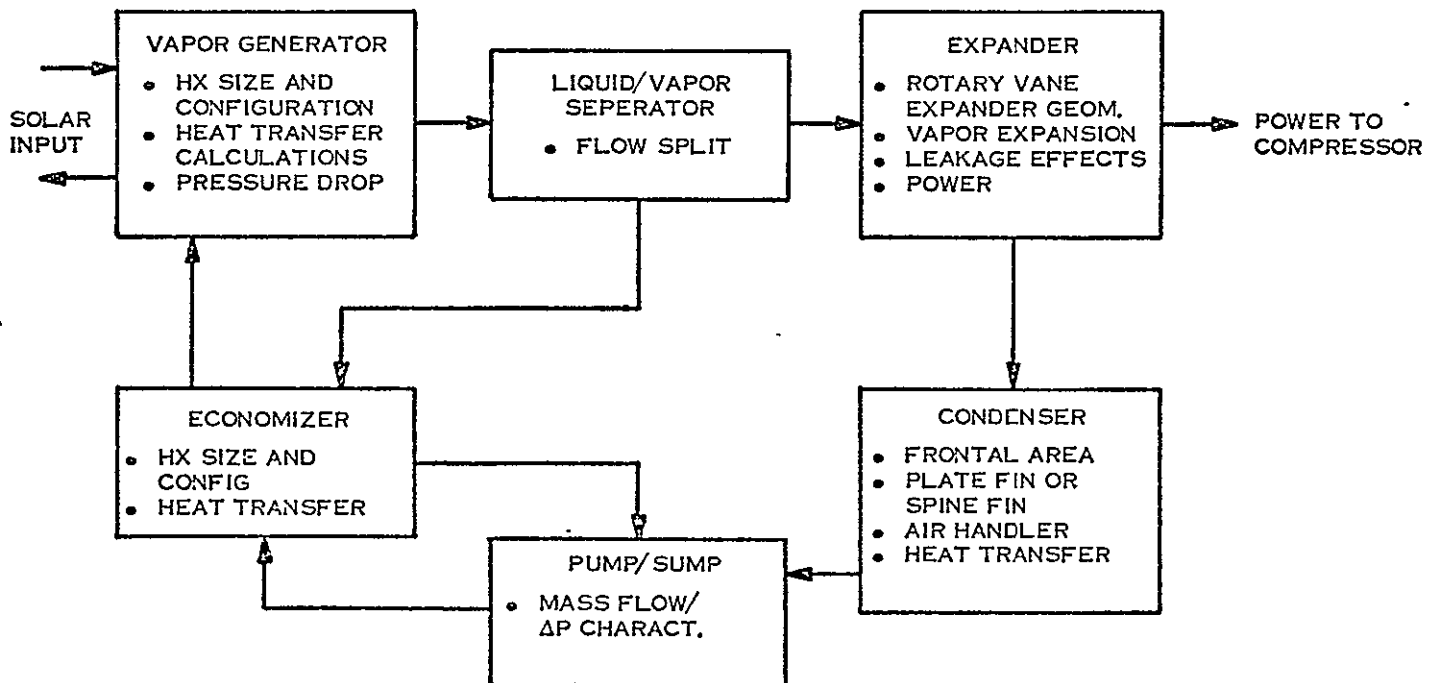
The major development item for the heating and cooling system is the Low Temperature Rankine solar driven engine. A detailed LTR system analysis code was developed to provide performance simulations and provide the basis for component sizing in support of the hardware development.

Table 2.2-5 Sample of Solar Driven Machines Analyzed

OUTDOOR COIL	INDOOR COIL	COMPR	RPM	CFM	T _{AMB}	CAPACITY KBTUH	HORSE- POWER REQ'D	HORSE- POWER TON	CYCLE COOLING COP	SENSIBLE HEAT RATIO	T _{AIR} OUT
5 TON	3 TON	5 TON	1800	1200	95	45.7	4.93	1.29	3.64	0.71	57.8
4 TON	3 TON	4 TON	1800	1200	95	36.1	3.91	1.30	3.63	0.70	62.9
4 TON	2.5 TON	4 TON	1800	1050	95	34.5	3.92	1.36	3.46	0.63	60.9
4 TON	3 TON	3 TON	1800	1200	95	29.9	2.80	1.12	4.20	0.69	65.1
4 TON	3 TON	3 TON	1800	1050	95	29.2	2.72	1.12	4.28	0.68	63.5
5 TON	5 TON	2.5 TON	1800	1200	95	30.0	2.50	1.00	4.62	0.70	65.6

INDOOR DESIGN CONDITIONS: 80° F DRY BULB
67° F WET BULB
60% RH

- TONNAGE REFERS TO CAPACITY BASED ON STANDARD RATING CONDITIONS



- INPUTS**
- COMPONENT SIZE, GEOM.
 - OUTDOOR CONDITIONS
 - SOLAR INTERFACE COND.

- OUTPUTS**
- CYCLE STATE POINTS, MASS FLOWS
 - COMPONENT PERFORMANCE
 - POWER AND TORQUE TO COMPRESSOR
 - CONDENSER AND PUMP POWER REQ'TS

Figure 2.2-23 LTR System Analysis Code

ORIGINAL PAGE IS
OF POOR QUALITY

The LTR code was assembled around detailed models of the hardware making up the LTR loop. Figure 2.2-23 contains a functional description of the LTR analysis code. The layout as shown in Figure 2.2-23 is representative of the refrigerant flow and the components making up the LTR system.

The code solves for a steady state system condition using fixed boundary conditions of ambient temperatures and hot water temperature into the vapor generator from the solar loop. The code defines the cycle state points (temperature and pressure), mass flows, component performance, parasitic power requirements, and power and torque available to the drive the heat pump compressor.

The inputs are varied to cover the range of possible operating environments. The power output is compared to the heat pump compressor requirements at similar environmental conditions. An operating map results from the comparison which defines boiler input temperatures, ambient condition and cooling capacity limits. The map is used in the system simulation code to obtain the cooling energy supplied by the solar system.

2.2.2.4 Heating and Cooling System Trades

Additional trade studies will be conducted in the next time period after completion of the definition of the LTR performance characteristics. The trade studies will include:

1. Percent of heating and cooling satisfied by solar system (SBSS) as a function of collector area
2. Percent of heating and cooling SBSS as a function of storage volume in the hot

TES

3. Percent of cooling SBSS as a function of storage volume in the LTES
4. Percent of heating and cooling as a function of HX-1 size
5. Repeat of (4) for HX-2 if baseline remains preferred approach
6. Transport loop pumping power vs vapor quality at exit of vapor generator

The trade studies will be conducted for the following system configurations:

1. S/E DHP using a chilled/hot water evaporator
2. S/E DHP using a DX coil as an evaporator
3. Using a Motor Boost mode in which an electric motor is used in conjunction with the solar engine to share the load.

2.3 SYSTEM DEVELOPMENT (WBS 1.2.2)

2.3.1 HEATING SYSTEMS (WBS 1.2.2.1)

2.3.1.1 Collector (WBS 1.2.2.1.1)

The collector development task includes the design and performance verification of the basic collector, the design activities related to integrating the collector into standard roof structures and the design and development of a heat transfer loop of which the collector forms a part. Activities in all three areas have been initiated during the first reporting quarter for the contract effort and significant accomplishments are summarized in the following paragraphs. As proposed, the design approach is to use the TC-100 evacuated tube solar collector.

2.3.1.1.1 Collector Design and Performance Verification

2.3.1.1.1.1 Collector Design. The engineering design of the basic collector has been a part of the continuing GE - funded effort in the area of collector product design and was essentially complete at the onset of the contract effort. However, although a design definition existed, there are some key areas which require further development as either a product improvement or a cost reduction feature. These areas are described briefly as follows:

1. Reflector - The engineering design utilizes an anodized electrodeposited aluminum reflector. To prevent dissimilar metal corrosion, an aluminum frame is also specified. The aluminum frame will require special strutting to withstand environmental loads. It is desirable to incorporate a steel frame which will require the use of a different reflector material or the use of isolation techniques at the frame/reflector interface. Both options are being investigated.

2. Serpentine/Fin Attachment - The engineering design specifies the use of a $\frac{1}{4}$ -inch OD steel tube and a 0.004-inch thick copper fin. Method of attachment of the fin to the tube is specified as a braze. The specific technique for brazing must be developed. Furnace brazing, and automatic torch brazing are both being pursued along with ultrasonic welding and mechanical fastening. Successful samples of ultrasonic welding have been received.
3. Protective Cover - The baseline collector design does not include the use of a protective cover based on test results which have indicated that a cover may not be required. However, it is definitely possible that a cover will be required in some localized installations. Therefore, an activity has been started to develop a protective cover. To date, thin film Lexan R and open mesh screen have been identified as candidates with the Lexan R being selected prime for more universal utilization. Other areas of development activity related to the design include shipping packages, frame mounting points and insulation selection and verification.

2.3.1.1.1.2 Collector Performance Verification. Performance verification has been initiated using both full scale operating modules and three tube stagnation modules. The operating module has validated the shroud design and serpentine interface approach while the stagnation tests have verified the selection of the reflector and yielded positive indications that the overall collector will perform as designed.

The module tests were run on a 4-foot by 4-foot module using final shroud configurations and the specified manifold design. The reflector however, was a aluminized mylar reflector which deteriorated rapidly when exposed to weather. The deterioration of the reflector was due to the dissimilar metal contact between the aluminum and the zinc on the baseplate. Unfortunately, the deterioration reduced the value of the module toward verifying the overall collector performance.

The 4-foot by 4-foot module was used to verify shroud and shroud/serpentine performance however. The degraded reflector surface was covered with a flat black material, and

the collector was operated. Figure 2.3-1 represents the results of these tests. The computer code used to predict the collector module was adjusted to predict performance without the reflector ($P_R = 0$). The test data was then plotted against predicted results. The test data exceeded the predicted performance in most cases except at the higher operation temperatures where data accuracy was questionable due to the problems of maintaining steady conditions at the elevated temperatures. Conclusions drawn from the testing were as follows:

1. The shroud, as designed, meets or exceeds specified performance levels.
2. The serpentine-to-shroud interface does allow for the appropriate heat transfer from the glass to the liquid. The calculated ΔT from glass to fin of 10°F appears validated by the above tests.
3. It will be necessary to rebuild the test stand-in order to obtain accurate data up to 300°F .

The stagnation test modules consisted of three tubes each mounted in a mini-reflector of three troughs. A copper fin with thermocouples attached was slipped down the center shroud. The center shroud was most representative of a true collector in that it would receive any reflection from adjacent tubes. The shrouds were then allowed to reach stagnation conditions. Variations in collector orientation and reflector surfaces were then introduced. Results of the variations were compared to determine the set affect of the variation. The tests resulted in the following conclusion.

1. Performance differences between silvered mirrors (~ 0.9) and polished aluminum (~ 0.8) were so insignificant that the more cost-effective aluminum reflector was chosen.

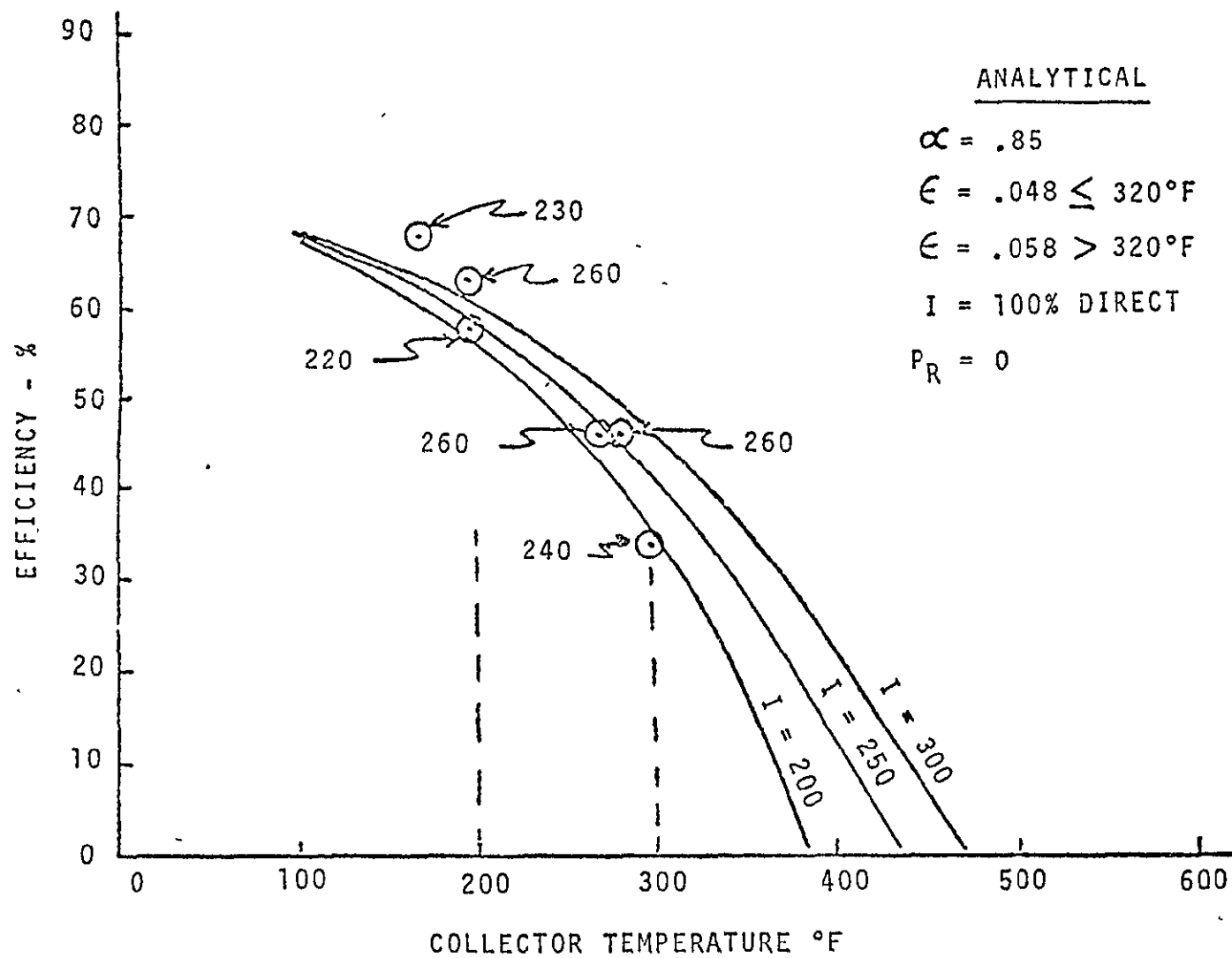


Figure 2.3-1. Shroud Test Data

2. The orientation of the collector can be either E-W or N-S without any significant affect on overall performance.
3. A diffuse reflector is not an optimum design. However, if the specular reflector degrades to a diffuse reflector, the collector will still perform satisfactory.

More detailed test results are discussed in paragraph 2.3.1.1.2.

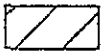
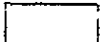
2.3.1.1.2 Collector Integration

The original mounting concept showed two collectors mounted with common manifold area in an E-W orientation. The E-W orientation was based on a reflector analysis that indicated its performance was enhanced in this orientation. However, the concept selected was only good for a short roof with the proper attitude angle. When all mounting possibilities are considered along with the probability of occurrence, a N-S orientation is favored. Table 2.3-1 summarizes the results of this study. The integration difficulty assessment is put into words such as difficult, simple, etc. This assessment is based wholly on technical difficulties with the major emphasis being manifolding and strutting and minor emphasis being placed on rain, snow, hail, wind, maintenance, and aesthetics. The shading shown on Table 2.3-1 is indicative of the integration difficulty combined with the probability of occurrence. If the integration was considered difficult, and it had a high probability of occurrence, then the assessment indicated that it was of major concern. The results of the study indicated very strongly that the N-S orientation was preferred.

The stagnation temperature tests were used to evaluate whether a severe penalty would result in the collectors were placed in a N-S orientation instead of an E-W orientation.

Table 2.3-1. Mounting Situation Summary

SITUATION	ANGLE CONFORMANCE		% OF COLLECTORS APPLIED TO SITUATION	INTEGRATION DIFFICULTY	
	ELEV	AZM		E - W	N - S
FLAT ROOF	NO	YES	VERY HIGH NEW AND RETRO	DIFFICULT	SIMPLE
FLAT FIELD	NO	YES	VERY HIGH NEW AND RETRO	DIFFICULT	SIMPLE
SLANT ROOF	YES	YES	HIGH NEW AND RETRO	SIMPLE	SIMPLE
SLANT ROOF	YES	NO	LOW TO MOD RETRO ONLY	DIFFICULT	DIFFICULT
SLANT ROOF	NO (+)	YES	VERY LOW RETRO ONLY	DIFFICULT	SOME DIFFICULTY
SLANT ROOF	NO (-)	YES	MODERATE NEW AND RETRO	DIFFICULT	SOME DIFFICULTY
SLANT ROOF	NO	NO	VERY LOW RETRO ONLY	EXTREMELY DIFFICULT	EXTREMELY DIFFICULT
INTEGRATED ROOF	YES	YES	VERY LOW NEW ONLY	VERY DIFFICULT	VERY DIFFICULT
INTEGRATED FACADE	YES	YES	LOW NEW AND RETRO	DEPENDS	DEPENDS

 MAJOR CONCERN
 MINOR CONCERN
 ACCEPTABLE

Three tubes with identical coating properties were placed on test simultaneously and tracked for stagnation temperatures. The three tubes were placed in an E-W trough, a N/S trough and a N-S diffuse reflector. The tests were first run at a zero declination angle at solar noon. Figure 2.3-2 shows the stagnation true temperatures for all three modules. The temperature traces are identical to predictions. The temperatures were then reduced to energy curves by simply integrating the time at temperature. The results are shown in Figure 2.3-3. As predicted, the E-W orientation was better than the N-S and both were better than the diffuse reflector.

However, it was impressive as to how both the N-S oriented tubes come up in temperature earlier in the morning. It was decided that the absorbtance depending on the incident angle was significant therefore, additional tests were run with the same three modules, but at different declination angles. Figures 2.3-4 and 2.3-5 are indicative of the data tubes at different declination angles. As the declination angle at solar noon increases, the E-W arrangement degraded faster than the N-S until at the 24° S declination angle, the N-S was significantly better than the E-W. An integration of the degradation factor over a full year on a fixed collector indicated that the N-S orientation would not result in a significant performance penalty therefore, because of the overall easier integration capabilities - the N-S orientation, it has been chosen as the orientation for all future integration studies.

The overall integration effort has been identified as being a significant activity in designing cost effective collector systems. Factory built standardized hardware will have to be designed for all types of integration conditions in order to reduce installation costs.

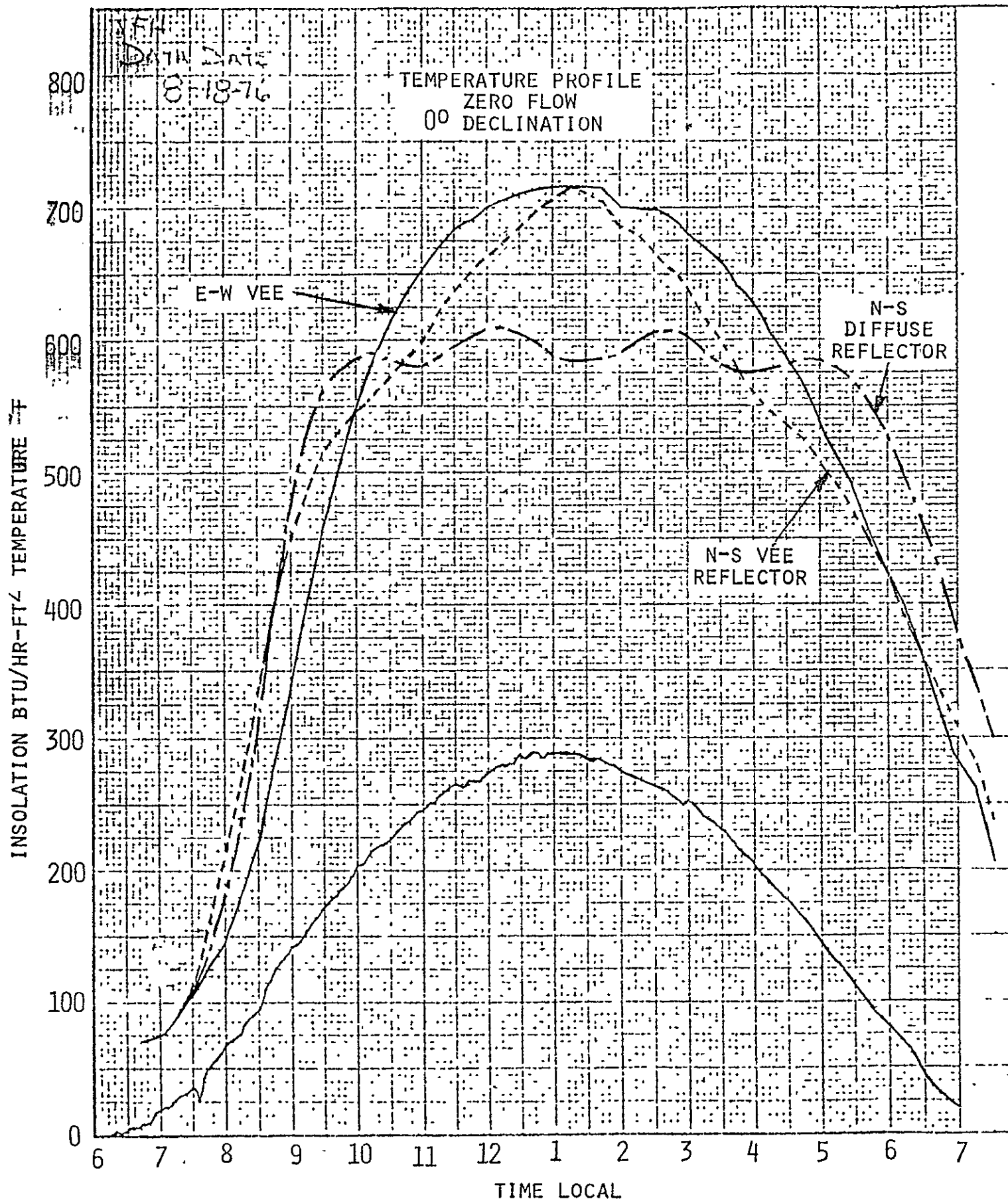


Figure 2.3-2. Temperature Profile Zero
Flow 0° Declination

JFH

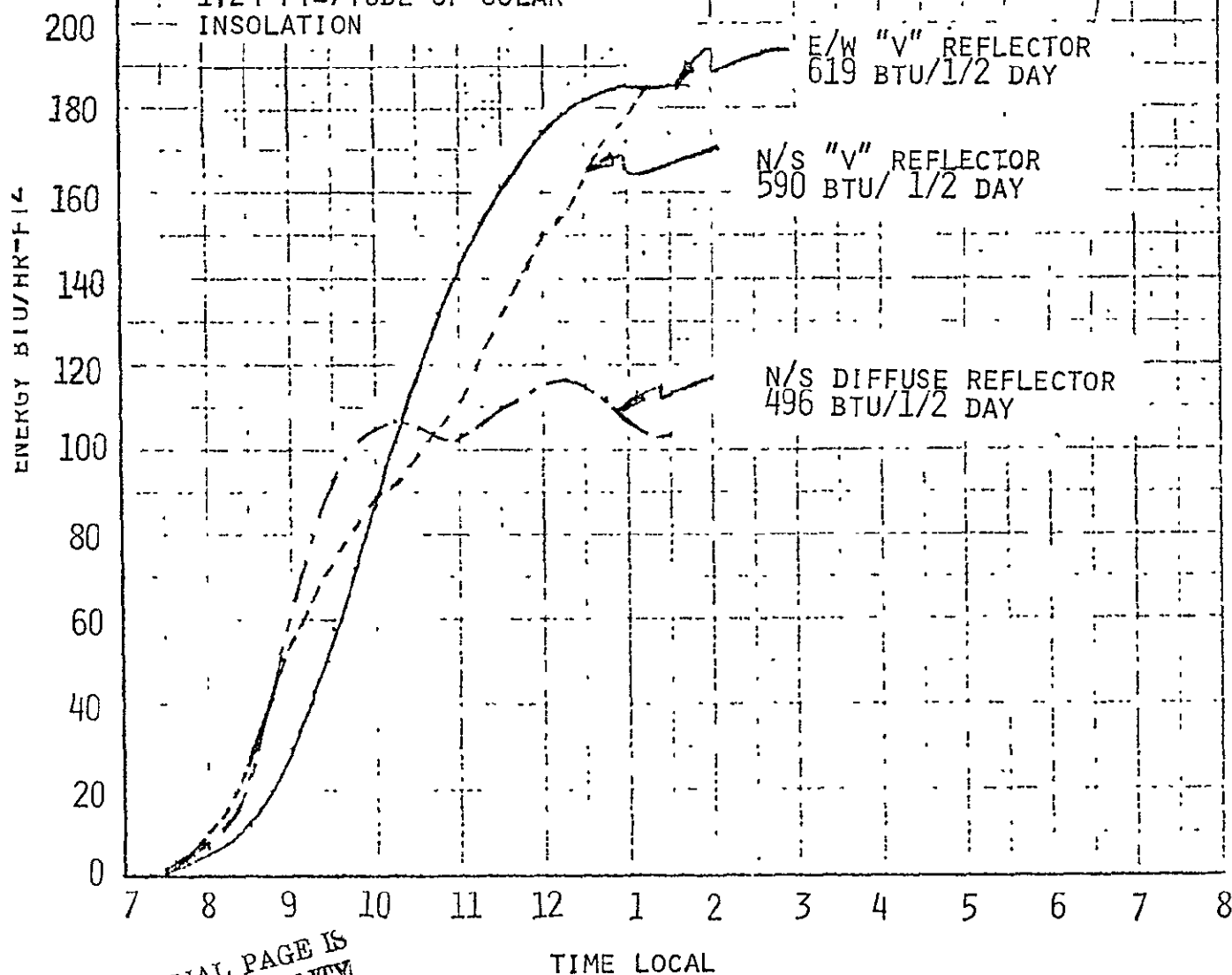
DATA DATE
8-18-76

ENERGY EMITTED FROM
THE INNER GLASS TUBE
PER FT² OF TUBE SURFACE
VS
TIME OF DAY

ARRAY WAS SITUATED TO
HAVE 0° DECLINATION ANGLE
FOR DIRECT RADIATION INCIDENT
ON THE ARRAY

"V" REFLECTOR ARRAYS INTERCEPT
1.58 FT²/TUBE

DIFFUSE ARRAY INTERCEPT
1.24 FT²/TUBE OF SOLAR
INSOLATION



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 2.3-3. Energy Emitted from the
Inner Glass Tube Per ft² of Tube
Surface vs Time of Day

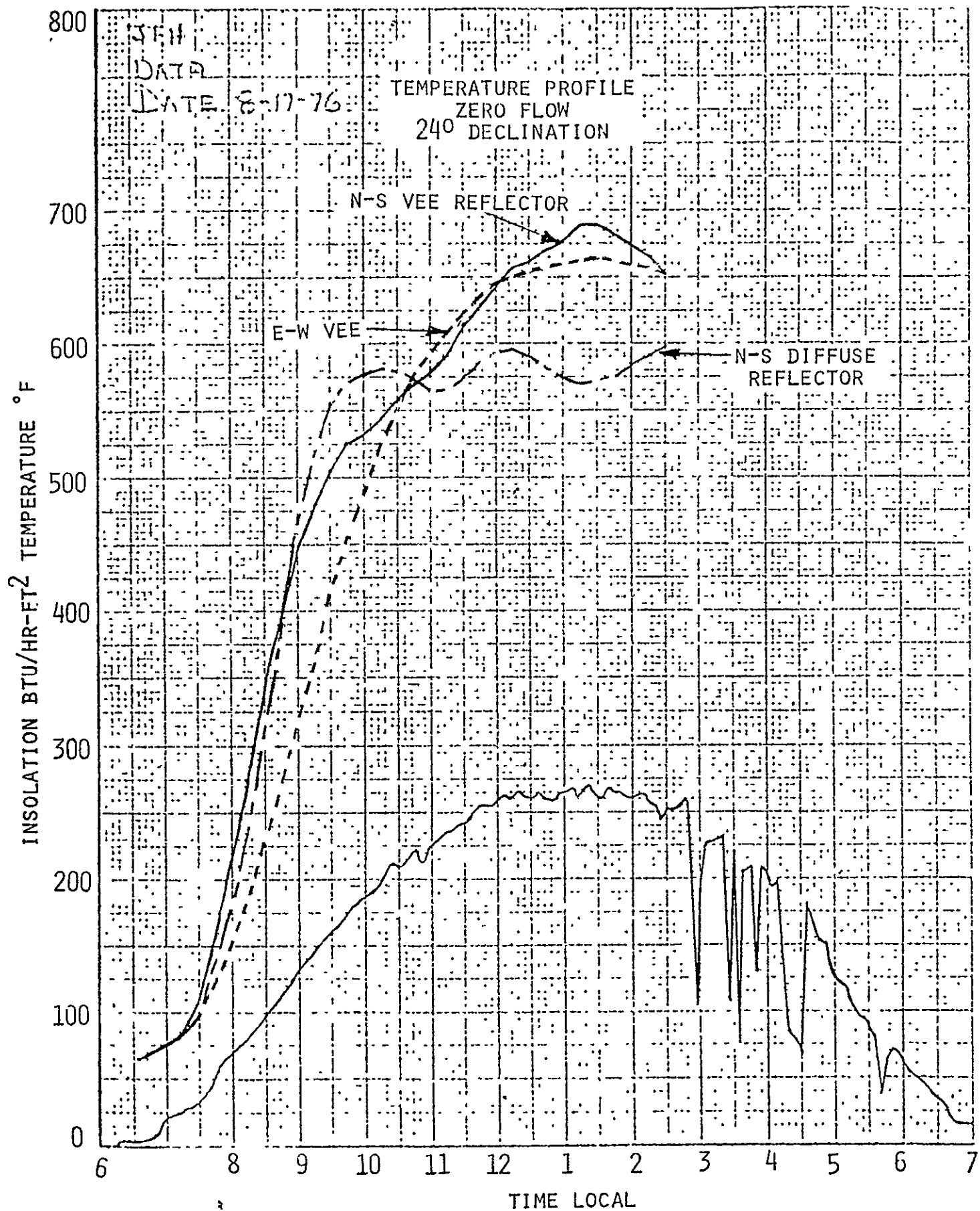


Figure 2.3-4. Temperature Profile Zero
Flow 24° Declination

DATA DATE
8-17-76

ENERGY EMITTED FROM THE
INNER GLASS TUBE PER FT²
OF TUBE SURFACE
VS
TIME OF DAY

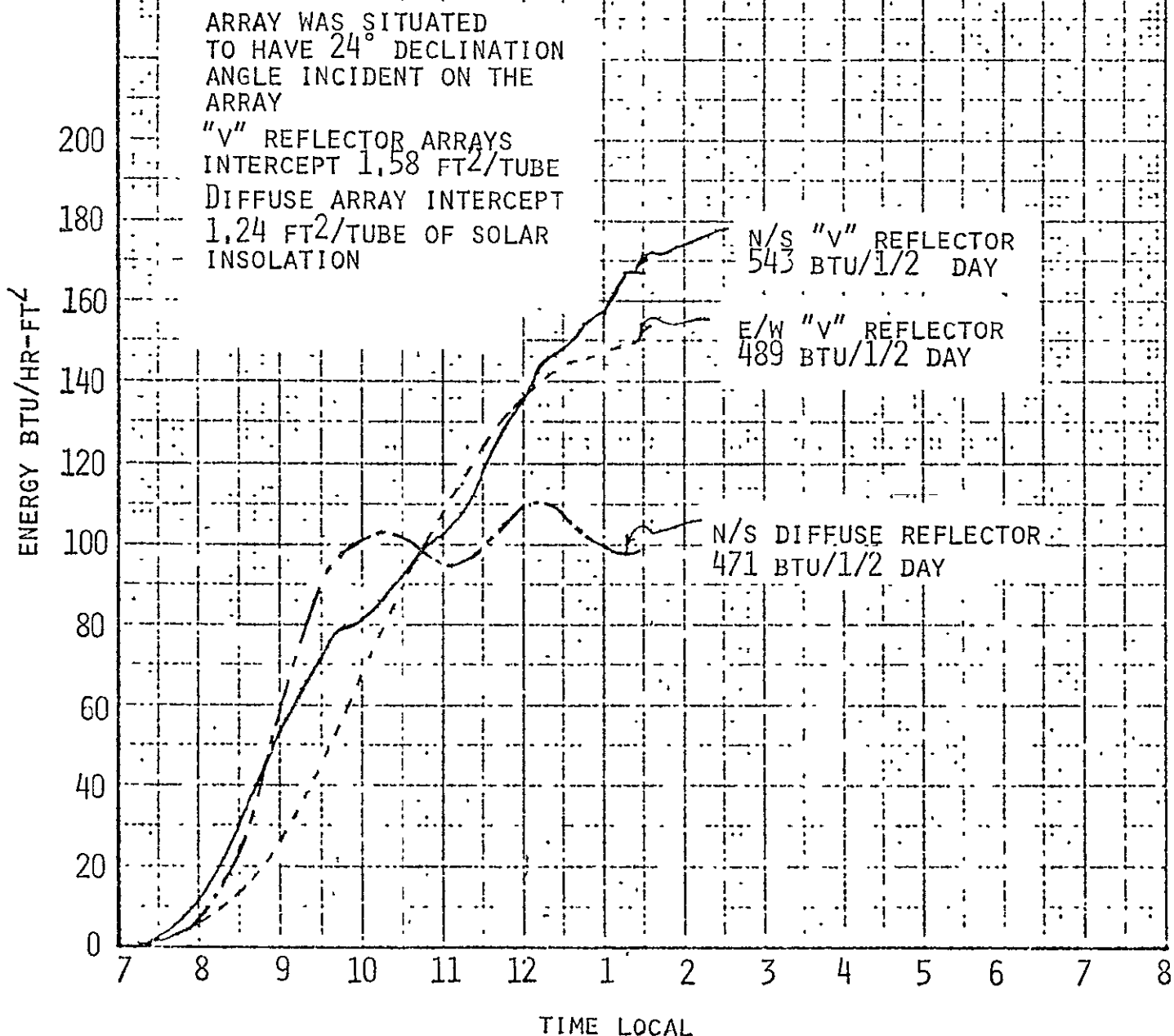


Figure 2.3-5. Energy Emitted from the Inner
Glass Tube per ft² of Tube Surface
vs Time of Day

ORIGINAL PAGE IS
OF POOR QUALITY

2.3.1.1.3 Collector Primary Loop

The high stagnation temperatures of the evacuated tubular collector requires special consideration for the design of the loop in which it will operate. Selection of a fluid is paramount to the operation. Several problems come to light when the basic requirements of the loop are considered. These requirements are:

1. The loop will not freeze
2. The loop must survive zero flow conditions
3. The loop must charge the TES to 250°F, and
4. The loop must be cost effective for both installation and operation.

A comprehensive study of loop configurations for various fluids was performed to determine the best approach for the loop. The results of this study are summarized in Table 2.3-2. Of all the candidates, only aqueous antifreeze fluid appears feasible and, ethylene glycol is the preferred fluid.

Use of ethylene glycol requires special provisions within the loop. If the collector was filled with mixture during stagnation temperature, the pressure could build up to 3200 psi and the ethylene glycol would break down at the resulting temperatures. Since the N-S orientation makes it virtually impossible to completely drain the collectors, provision must be incorporated to allow the liquid to boil out of the collector.

ORIGINAL PAGE IS
OF POOR QUALITY

Table 2.3-2. Fluids Option Matrix

FLUID	FREEZE PROTECTION	STAGNATION TEMP AFFECTS	LOOP REQUIREMENTS	OVERALL FEASIBILITY
AIR	EXCELLENT	NONE	. LARGE DUCTS . 10% PARASITIC POWER LOSS	POOR
WATER	NONE	3200 PSI	. DRAINDOWN FOR FREEZING . BLOWDOWN FOR STAG	UNACCEPTABLE
ANTIFREEZE MIXTURE	FAIR TO GOOD	. 3200 PSI PRESSURE . FLUID CRACKS	. BLOWDOWN REQUIRED FOR STAG	FAIR TO GOOD
SILICONE OIL	EXCELLENT	. FLUID BREAKS DOWN	. DRAINDOWN REQUIRED FOR STAG . NO LEAKS ACCEPTABLE	UNACCEPTABLE
FREON (REFRIG.)	FAIR	. VERY HIGH PRESSURES . VAPOR BREAKS DOWN	CAN'T BE BUILT	UNACCEPTABLE
DOWTHERM J	EXCELLENT	. FLAMMABLE MIXTURE . HIGH PRESSURE	. HIGH RELIABILITY	POOR
THERMINOL 66	FAIR	. FLAMMABLE MIXTURE . HIGH PRESSURE	. HIGH RELIABILITY	POOR

ETHYLENE GLYCOL/WATER	FAIR	LIQUID E.G. BREAKS DOWN	. BLOWDOWN RQD FOR STAG . LOOP PRESSURE BELOW 30 PSIG	FAIR TO GOOD
ALCOHOL WATER	GOOD	LIQUID BREAKS DOWN	. BLOWDOWN RQD FOR STAG . FLUID MUST BE <u>BUFFERED</u>	FAIR

Figure 2.3-6 shows the loop configuration selected. The components and their functions are briefly described below:

1. Pump - circulate the fluid
2. VV2 - vent valve that closes as the pump operates and opens when the pump is off.
3. Expansion Tank - reservoir for liquid inventory when collectors are drained.
4. VV1 - A vacuum breaker which can also serve to release noncondensables.
5. S - A safety valve to prevent overpressure.
6. Vapor Condensor - A cold area that reduces the partial pressure of working fluid vapor and allows the collector to operate as a gravity feed heat pipe.

The entire loop operation is based on a gravity feed heat pipe. When the TES is charged, the pump is shut off and VV2 is opened. The loop then consists of three legged manometer. Liquid drains down the collector leg and begins to fill the expansion tank. Some of the liquid in the collector will siphon off, but some may remain. This liquid will boil off and condense out at the coldest point in the loop, which by design should be in the vapor condensor. This liquid is removed from the collectors until they are dry and the loop pressure will not increase.

The successful operation of the system will be based on the ability of the ethylene glycol to boil off without damage and by proper sizing of the loop components. An intensive materials evaluation is now in progress in both areas.

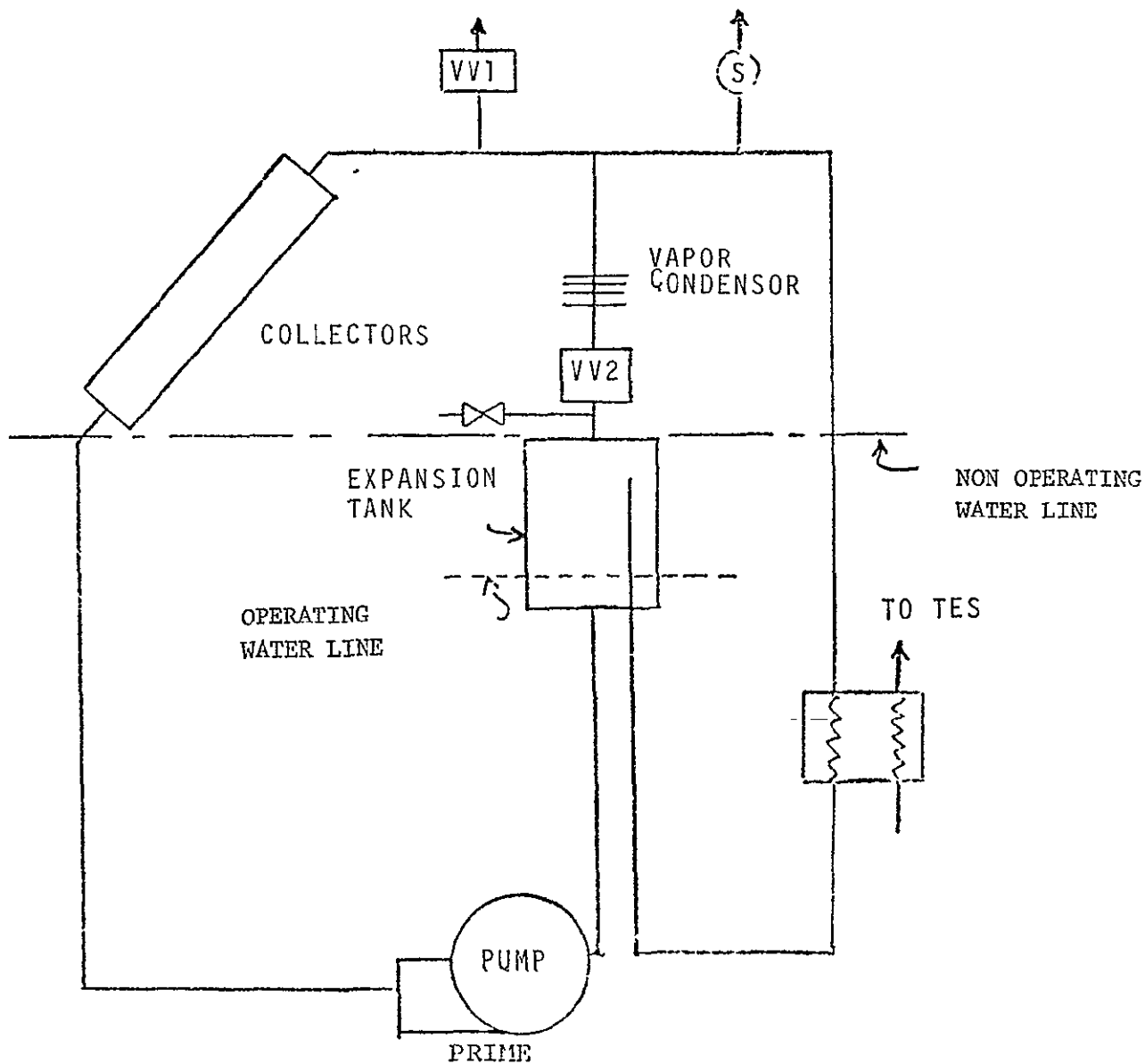


Figure 2.3-6. Least Restrictive Solar Loop

2.3.1.2 "All Other" Components, Heating Systems (WBS 1.2.2.1.2 thru 1.2.2.1.6)

"All Other" includes conventional items such as:

- . PUMPS
- . TANKS (TES, ETC.)
- . VALVES
- . PIPING
- . HEAT EXCHANGER
- . AUX. HEAT
- . DHW

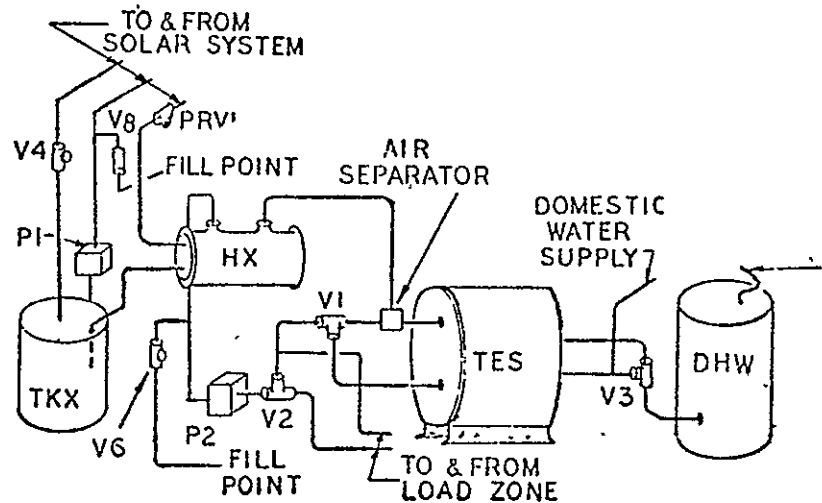


Figure 2.3-7. Subsystem Concepts - "All Other"

2.3.1.2.1 Introduction

During this reporting period, the main work performed in the "All Other" components area has been to further investigate and define technical concerns identified in the SHACOB Proposal and to consider cost/performance factors involved in implementing the system "building blocks" approach. The technical performance challenges are minor, and are chiefly concerned with sealing at temperatures up to 260°F, achieving 15 year life for the active components and finding a satisfactory outdoor insulation.

The cost challenges are of major concern, since these components are generally mature products whose costs will not go down with the large scale use of solar systems and they comprise a significant part of the total solar system cost. Therefore, approaches toward reducing their cost through designing for factory packaging of several items, standardizing sizes, selected-sources for high volume production and ap-

plication-oriented specifications are being pursued. In addition, studies are also being made on the feasibility of functional integration to reduce costs and increase performance such as combining the solar collector heat exchanger within the thermal storage tank.

Currently, the system/component performance characteristics have been defined, several specifications have been prepared and others are in progress as further indicated below.

2.3.1.2.2 Energy Storage Subsystem

Additional evaluation has been made on the selection of the thermal energy storage medium. The results of the study confirm the Proposal baseline selection of water as the storage medium based on experience, cost, compatibility with the system requirements and absence of technical and environmental concerns. A chart showing some of the basis for selection of water storage is shown in Table 2.3-3.

In addition, specifications 261A2250, Thermal Energy Storage Tanks, and 261A2251, Expansion Tanks, have been prepared. These specifications reflect the first iteration of the standard-sizing, multiple use concept.

2.3.1.3 Space Heating/Cooling

Specifications and studies are currently in process for components in this subsystem.

Table 2.3-3. Design Alternative Merit Rating Thermal Energy Storage Medium Selection

CRITERION	A	ALTERNATIVE B	C	D
PERFORMANCE	1	2	2	3
DEVELOPMENT RISK	2	3	2	1
SAFETY	3	3	1	1
MAINTAINABILITY	2	2	1	2
OPERATIONAL COMPLEXITY	2	2	2	1
MATERIALS COMPATIBILITY	2	2	2	2
PRODUCTION TOOLING	1	3	2	2
VOLUME PRODUCTION	1	3	2	2
LOW UNIT COST	2	3	2	1
LOW INSTALLATION COST	2	3	3	1
MIN. SYS./APPLICATION INFO	3	3	1	1
ECONOMY OF OPERATION	3	2	2	2
EQUIP. CAPITALIZATION COSTS	3	3	2	1
OPERATING LIFETIME	3	3	2	2
TOTAL	31	37	26	21

A. SENSIBLE HEAT, SOLID PHASE
 B. SENSIBLE HEAT, LIQUID PHASE, WATER
 C. SENSIBLE HEAT, LIQUID PHASE, OTHER
 D. LATENT HEAT, SOLID/LIQUID

2.3.1.4 Auxiliary Energy Subsystem

Specifications and studies are currently in process for components in this subsystem.

2.3.1.5 Hot Water Subsystem

Specifications and studies are currently in process for components in this subsystem.

2.3.1.6 Energy Transport Subsystem

Specification 261A2252, Collector Pumps, and 261A2253, Energy Transport Pumps, have been prepared. These specifications also reflect the approach to standard sizing and multiple use across the system "building blocks". Other component specifications in this area are in process.

2.3.1.7 Controls Subsystem (WBS 1.2.2.1.7)

System modes have been defined for the Heating-Only Systems. These modes are identified in the following lists and are shown in Figures 2.3-8 through 2.3-16. Included on each diagram is a list of operating conditions that satisfy the mode shown (i.e., S1-YES, P2-ON, etc.).

Heating Single Family (Figures 2.3-8 through 2.3-12)

1. Direct Solar Heating
2. Solar Boost
3. Heating from Storage
4. Storage Boost Heating
5. Storing Solar Energy

Heating Multi-Family and Commercial (Figures 2.3-13 through 2.3-16)

1. Direct Solar Heating from TES
2. Energy Storage
3. Stored Energy Use
4. Auxiliary Energy Use

Control of Heating-only system functions will be provided by a Controls Subsystem, shown in block diagrams form in Figure 2.3-17.

During the reporting period major emphasis was placed on selecting the type(s) of electronic devices and sensors that would best serve the Program's overall goals.

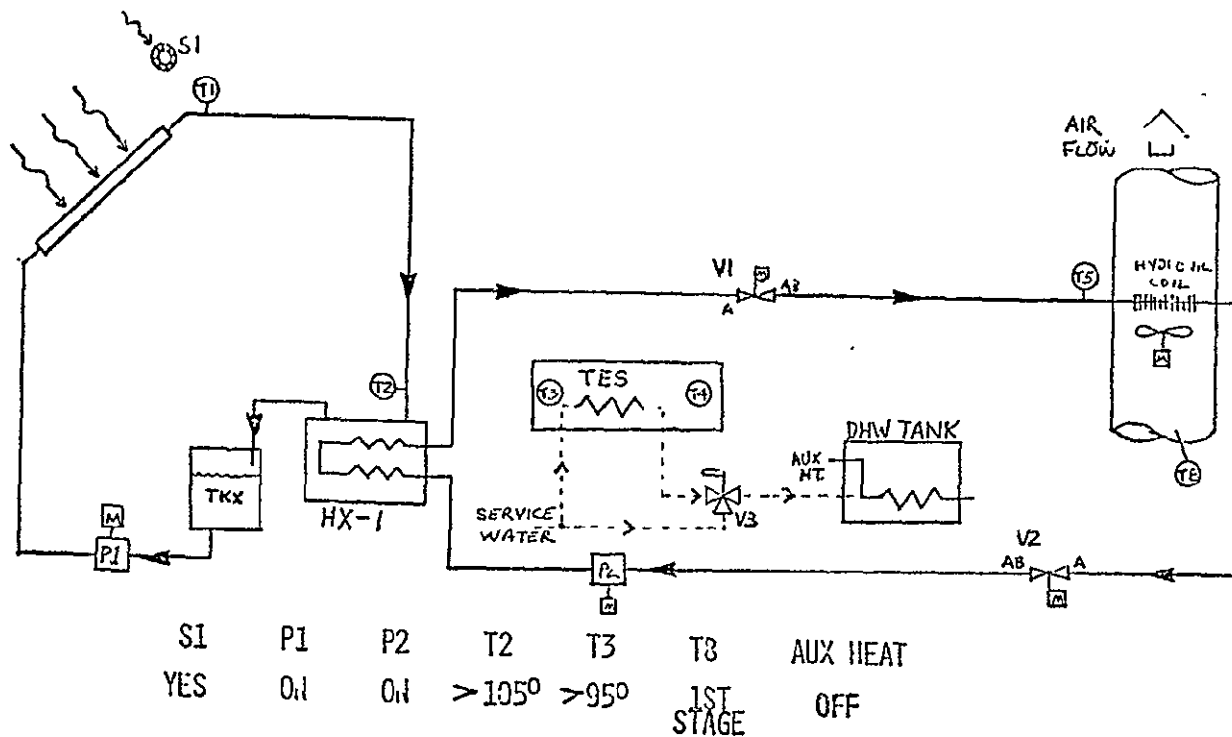


Figure 2.3-8. Direct Solar Heating (HSF)

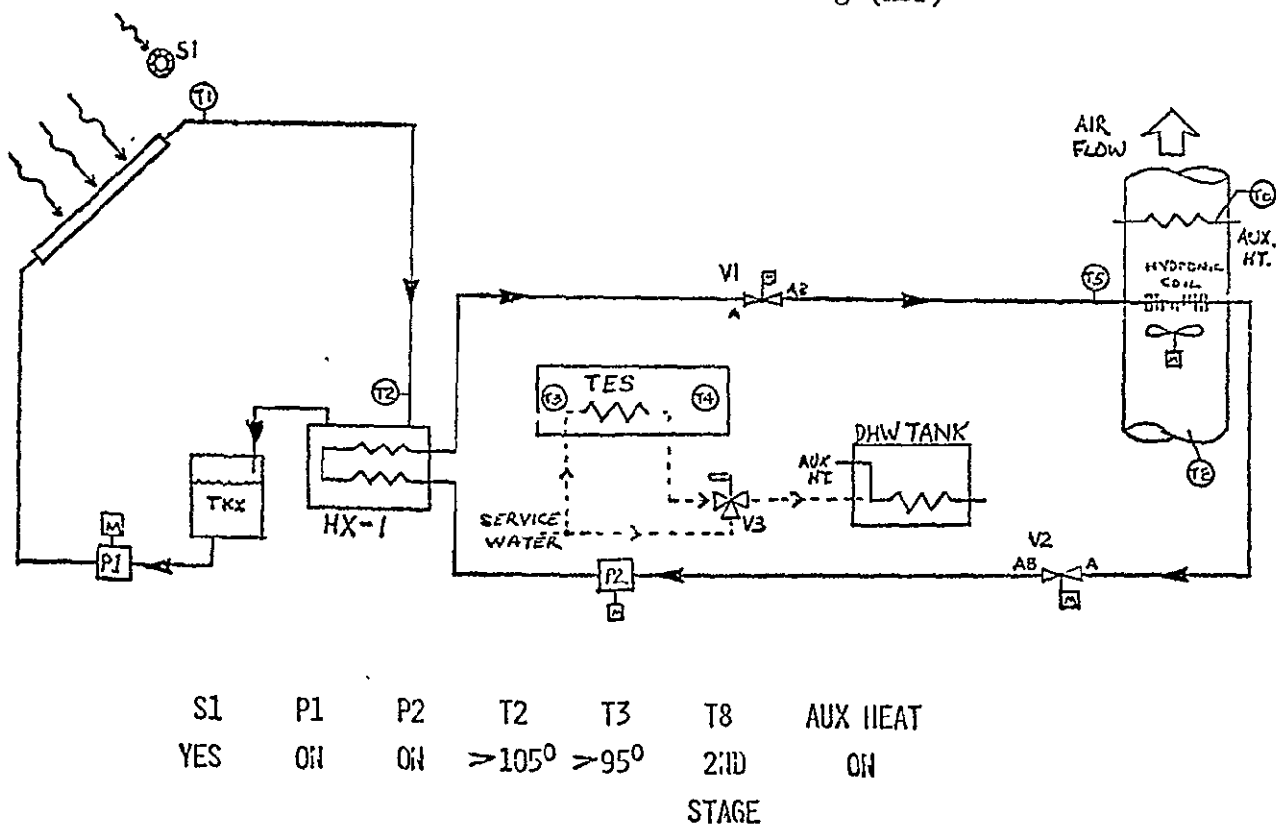


Figure 2.3-9. Solar Boost (HSF)

ORIGINAL PAGE IS
OF POOR QUALITY

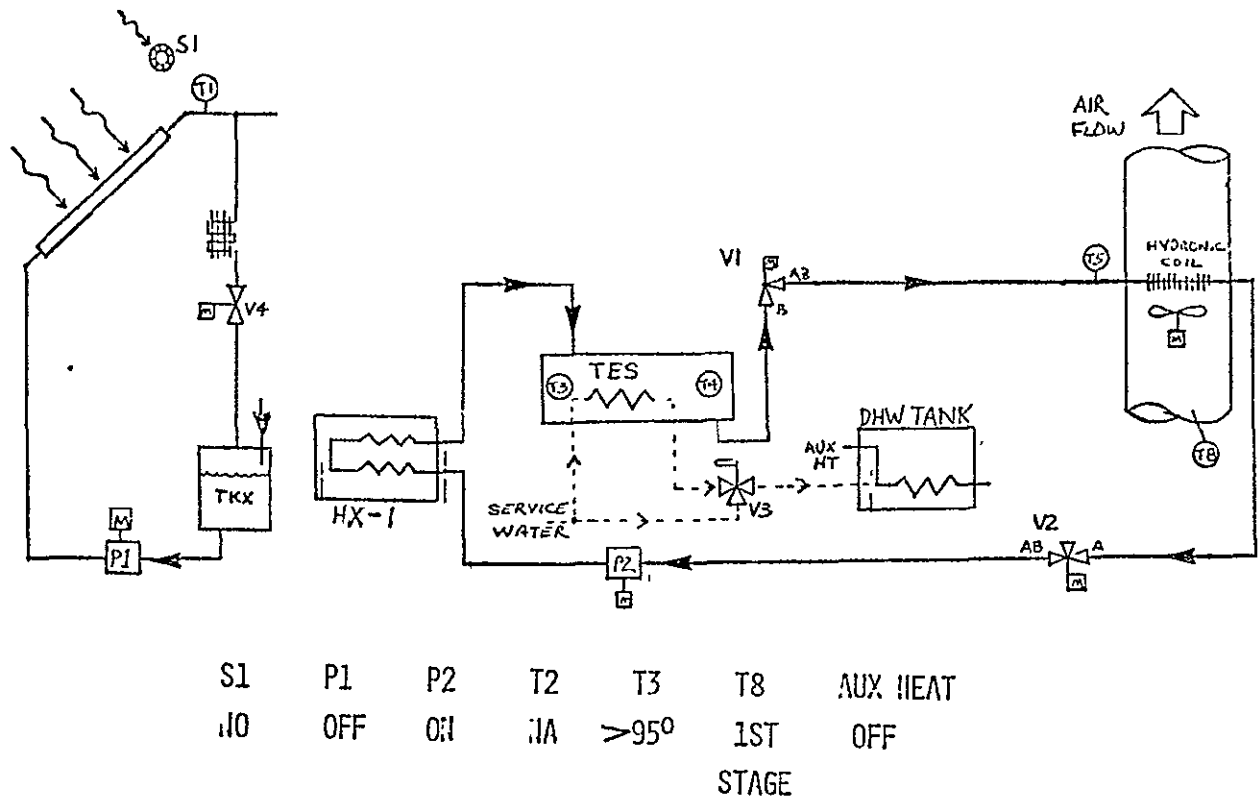


Figure 2.3-10. Heating from Storage (HSF)

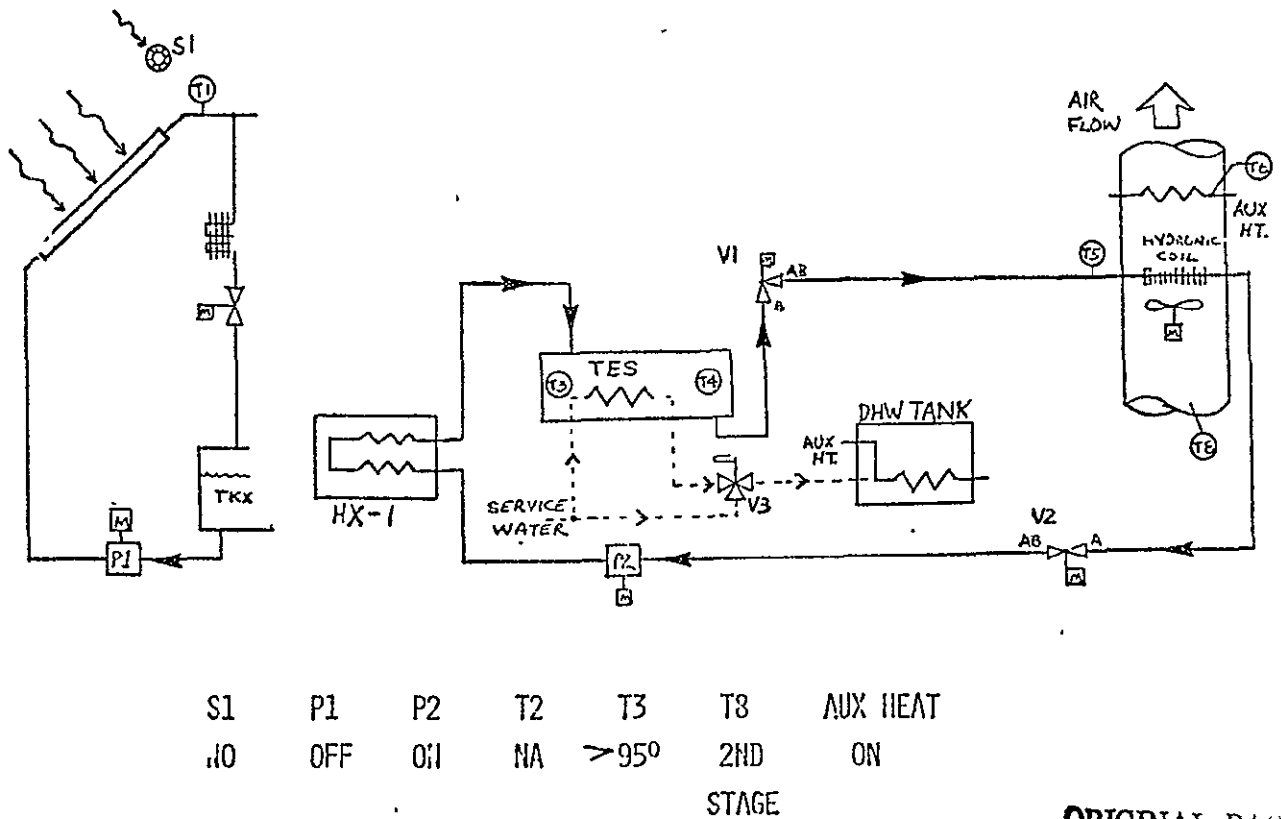


Figure 2.3-11. Storage Boost Heating (HSF)

ORIGINAL PAGE IS
OF POOR QUALITY

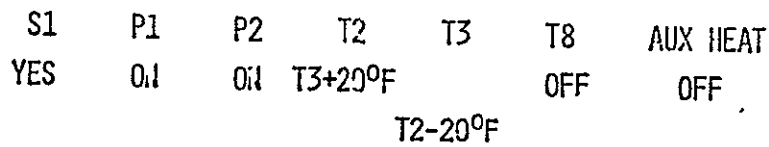


Figure 1-5 is a schematic diagram of a solar water heating system. The diagram shows a solar collector (S1) connected to a tank (TKX 1) via a pump (P1) and a valve (V4). The tank is connected to a heat exchanger (HX-1), which is connected to a hot water tank (HT TES) via a pump (P2). The hot water tank is connected to a DHW tank via a valve (V3). The DHW tank is connected to a service water line. The hot water tank is also connected to a circulator pump (P3) and a valve (V2). The circulator pump is connected to a series of hydronic coils (HYDRONIC COIL 1, HYDRONIC COIL N) via a valve (V7-1). The hydronic coils are connected to a return line via a valve (V7-N). The return line is connected to the hot water tank via a valve (V1). The hot water tank is also connected to an outdoor reset valve (T5B) and a temperature sensor (T5A). The outdoor reset valve is connected to a service water line. The hot water tank is also connected to a DHW tank via a valve (V3). The DHW tank is connected to a service water line.

S1	P1	P2	P3	T2	T3	AUX HEAT
On	On	On	ALWAYS	$T3 + 20^{\circ}$	SET	OFF
			On	POINT		

4-62

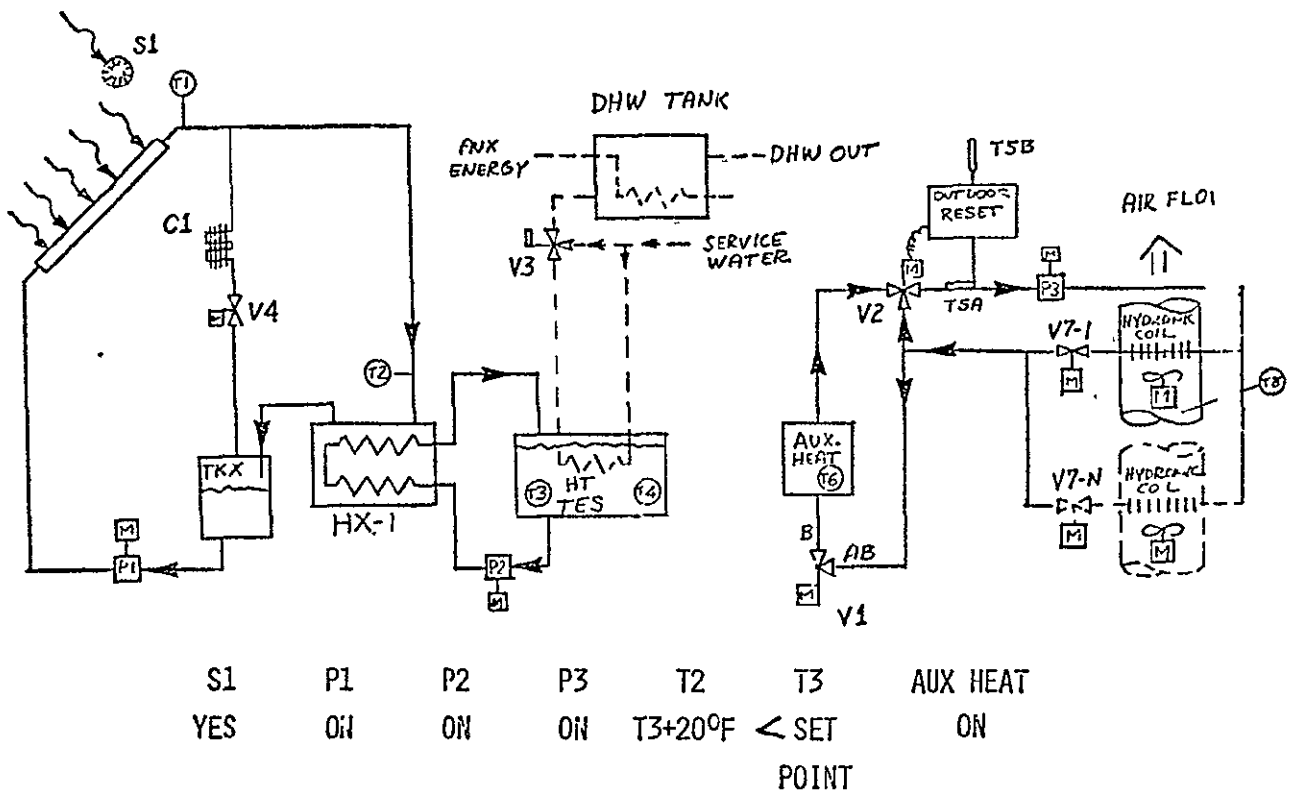


Figure 2.3-14. Energy Storage (HMF & COMM)

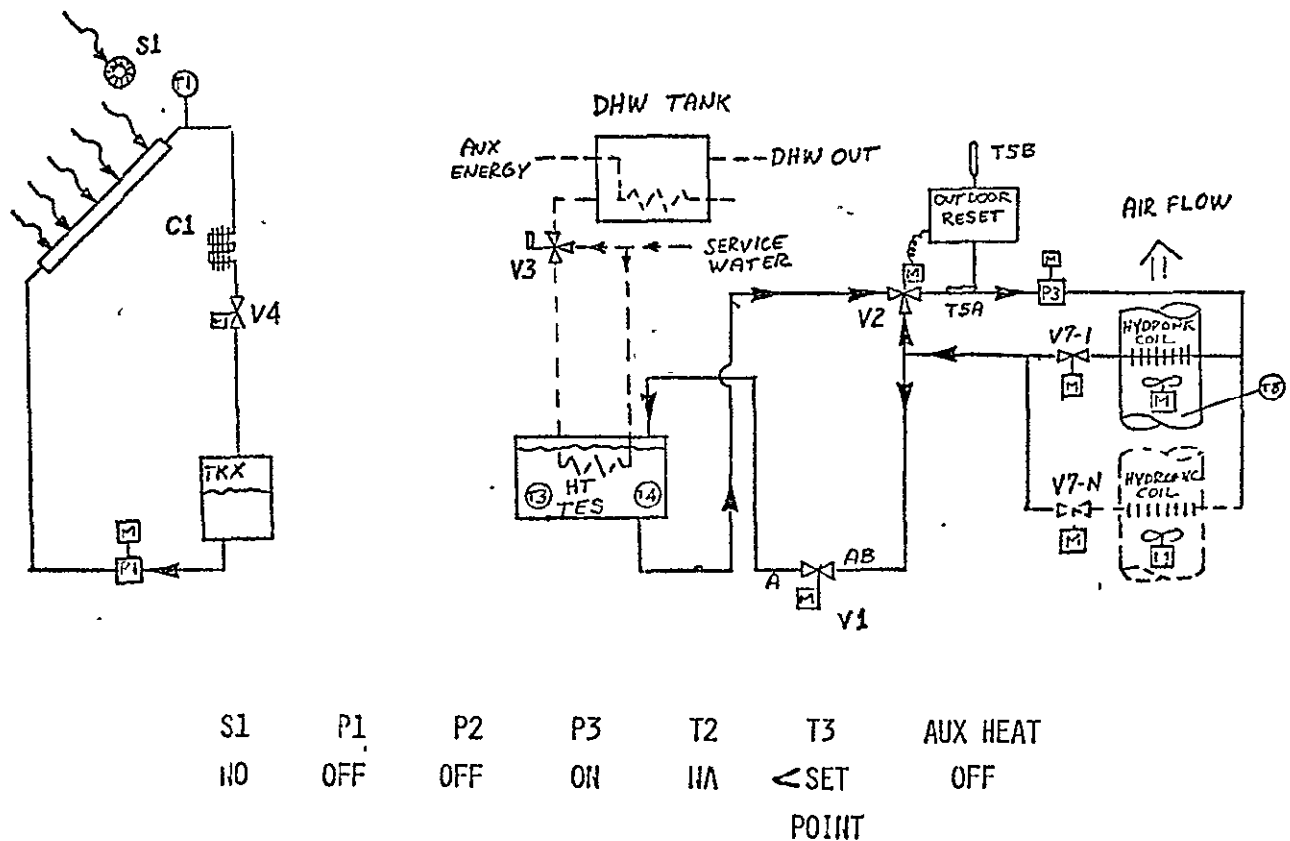


Figure 2.3-15. Stored Energy Use (HMF & COMM)

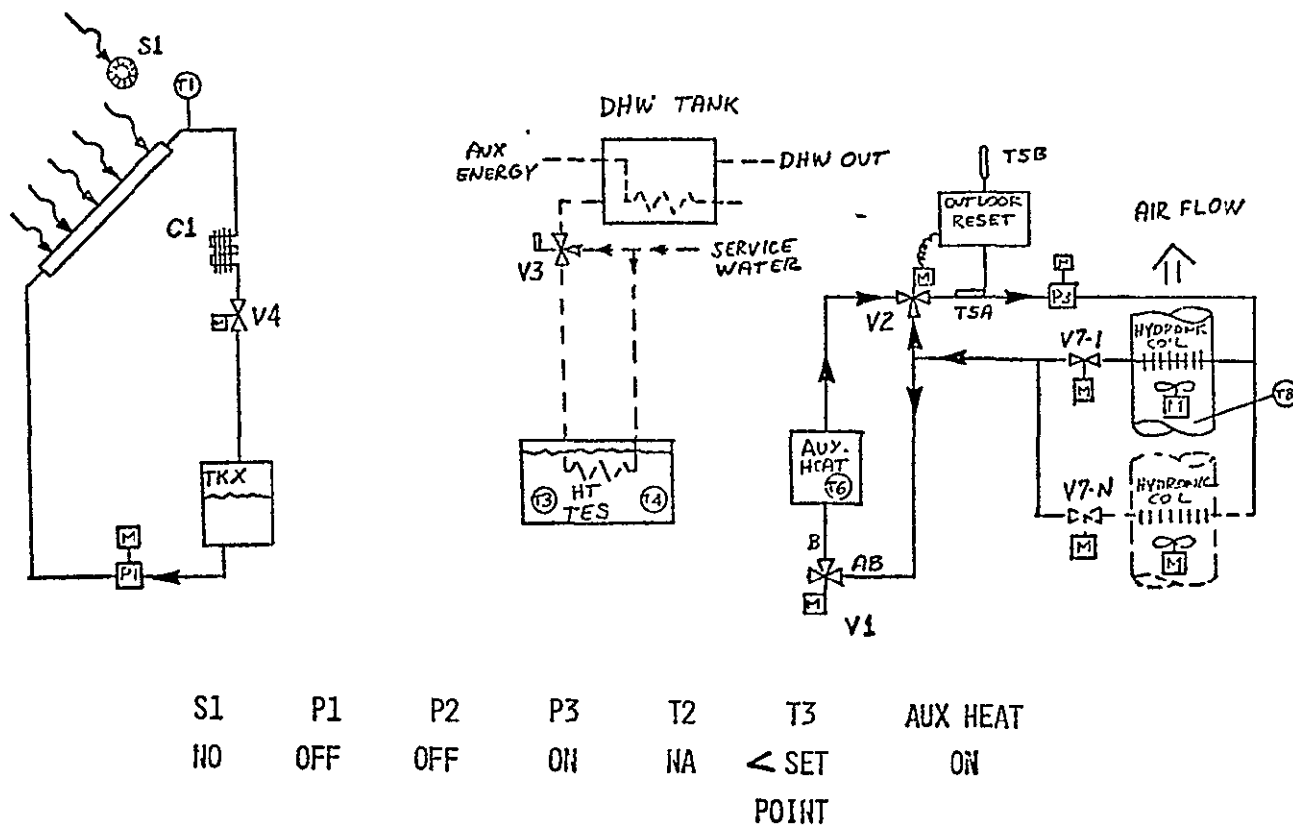


Figure 2.3-16. Auxiliary Energy Use (MHF & COMM)

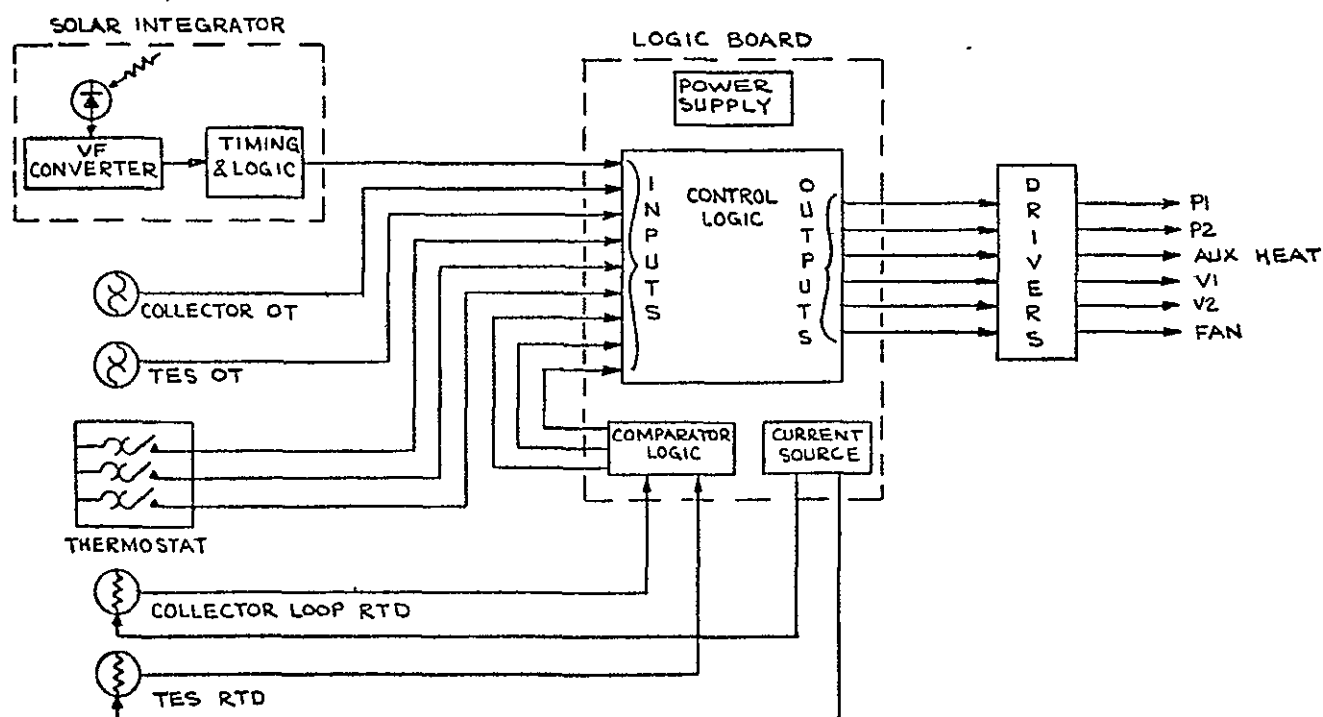


Figure 2.3-17. Controls Subsystem Block Diagram
(Typical for all Heating-Only Systems)

In the sensor area, Resistance Temperature Devices (RTD's) have been selected for linear temperature monitoring. RTD's of nickel provide a linear low cost alternative to thermistors. Standard bimetallic elements will provide temperature level sensing.

A solar sensor has been designed which uses a semiconductor sensor to input solar data to a digital integrator. This signal is used to initiate collector operation.

The electronic logic design will use a Field Programmable Logic Array. This is an IC which contains up to 48 logic functions. Analog signal conditioning will utilize standard linear IC's, however, the production design will incorporate a custom integrated circuit.

As a power interface from the logic signals to valve and motor operators, solid state switches (TRIACs) will be used. Relays will be inserted for high inductive loads (low power factors).

2.3.1.8 Electrical Subsystem

During the reporting period top-level electrical diagrams were generated for Single Family, Multi-Family, and Commercial Heating Systems. These diagrams are included as Figures 2.3-18 through 2.3-20 of this report. In general the approach chosen in defining the electrical subsystem was to:

1. Follow standard commercial practices
2. Maximize use of existing facilities
3. Follow the National Electrical Code

ORIGINAL PAGE IS
OF POOR QUALITY

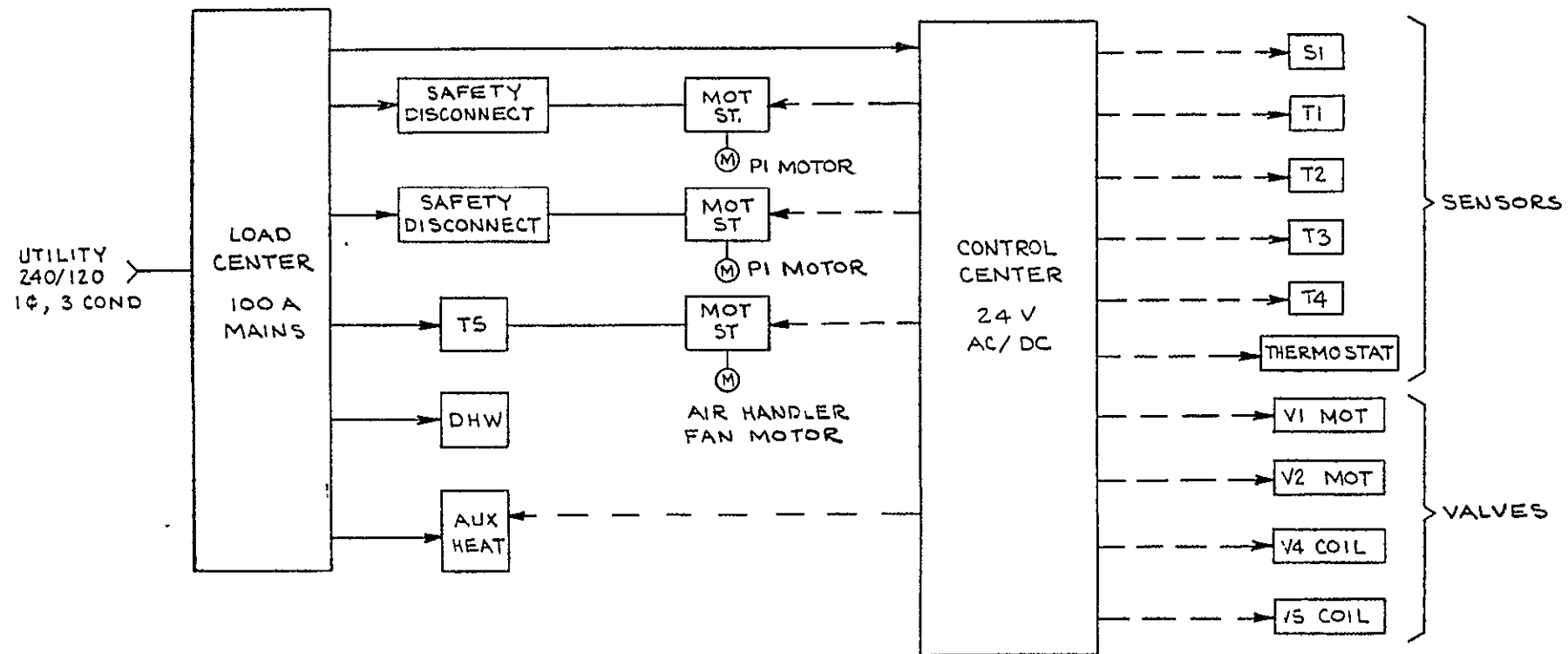
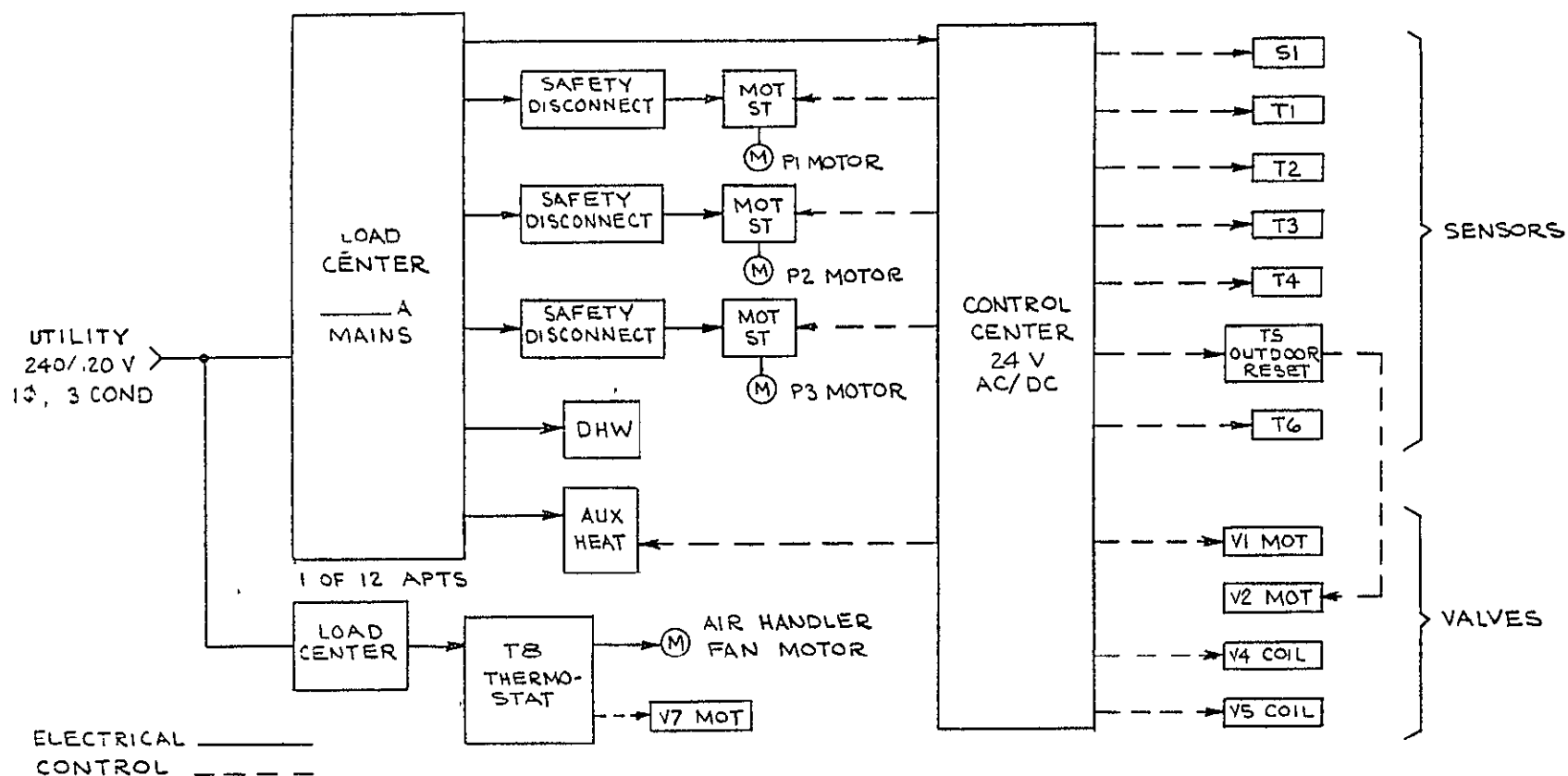


Figure 2.3-18. Electrical Diagram, HSF System



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 2.3-19. Electrical Diagram, HMF System

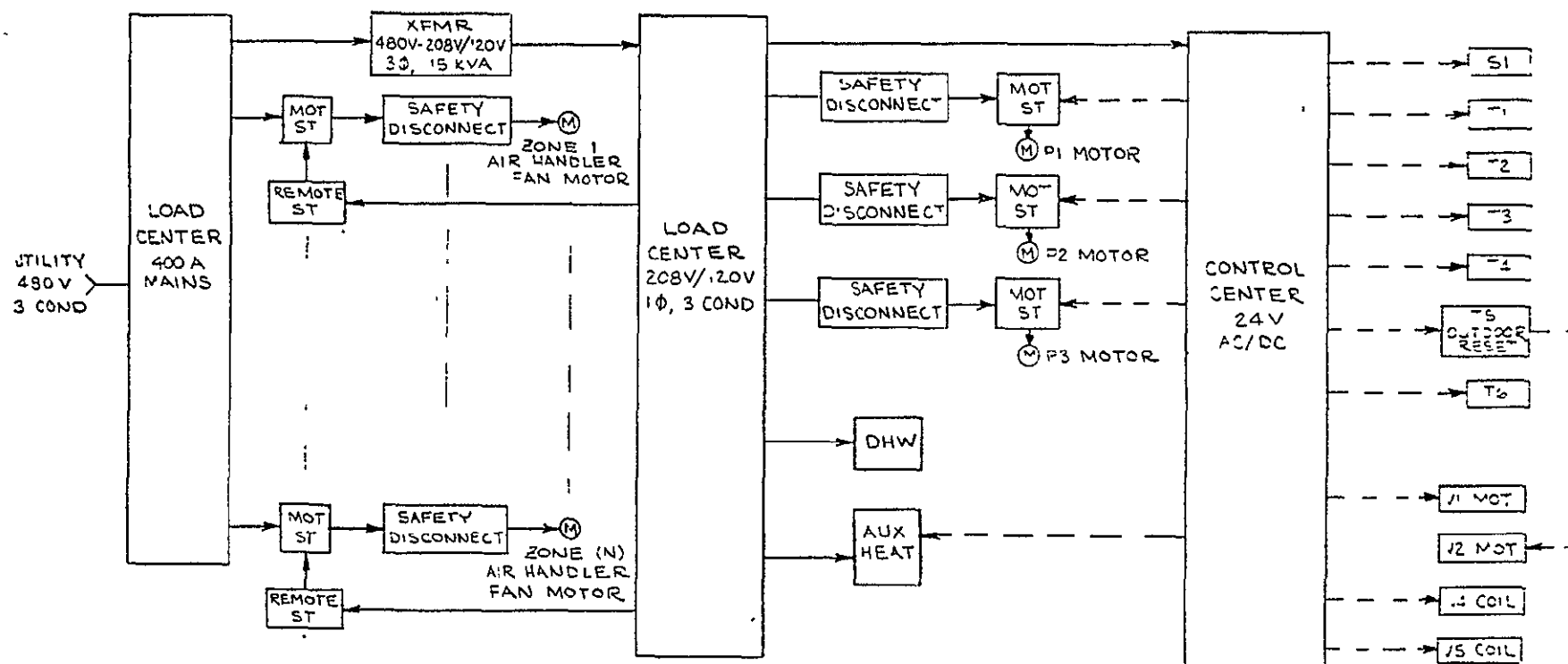


Figure 2.3-20. Electrical Diagram, HCOM System

2.3.1.9 System Integration (WBS 1.2.2.10)

Each of the systems to be delivered will be defined by a set of drawings and specifications. The general requirements specification (261 A 2 806) applies to all of the heating only and heating and cooling systems. Separate specification number will be used for the heating single family (261 A 2807), heating multi family (261 A 2808) and heating commercial (261 A 2809) systems. The specification will be uniquely applied to a particular building at a particular address by the use of a group number in the specification. For example the PDR package includes specification 261 A2807 G1, the G1 referring to the study model home in Madison, Wisc. Additional single family heating systems designed for particular homes in particular cities will have G2, G3,...at the end of the specification number. As the number of specifications increase a degree of commonality will evolve such that an existing specification can be made to apply to a new building.

Each system specification will include the following:

1. A system schematic diagram to define the type (or model) of the system (e.g., Figure 2.2-2)
2. Building designation and location to which system is to be applied.
3. Building interface drawing
4. A Master Parts List for the system
5. Weather data specification on which the performance is based
6. Minimum energy delivered by the solar system
7. Maximum auxiliary energy requirements.

The Master Parts List will include:

1. The installation drawing for the system
2. Installation Wiring Diagram
3. Electrical Schematic Diagrams
4. Control Subsystem Schematic
5. Mechanical Schematic Diagrams
6. Subsystem Top Assembly Drawings and subsystem specifications
(when applicable)

2.3.2. HEATING AND COOLING SYSTEMS (WBS 1.2.2.2)

2.3.2.1 Collectors

Refer to paragraph 2.3.1.1 Development carried out for heating system applies.

2.3.2.2 Energy Storage Subsystem

Refer to paragraph 2.3.1.2. Development of hot TES applies

2.3.2.3 Space Heating/Cooling Subsystem

Use of the heat pump results in different equipment for heating and cooling systems. Activity just starting.

2.3.2.4 Auxiliary Energy Subsystem

Equipment will be different for heating and cooling systems. Activity just starting.

2.3.2.5 Hot Water Subsystem

Refer to paragraph 2.3.1.5. Heating systems work is applicable.

2.3.2.6 Energy Transport Subsystem

Refer to paragraph 2.3.1.6. Heating system work is applicable.

2.3.2.7 Controls Subsystem

Refer to paragraph 2.3.1.7. Approach allows growth for cooling controls.

2.3.2.8 Electrical Subsystem

Refer to paragraph 2.3.1.8. Approach allows growth for cooling systems.

2.3.2.9 System Integration

Refer to paragraph 2.3.1.9. Activity not started this period.

2.3.2.10 Solar/Electric Driven Heat Pump (WBS 1.2.2.2.11)

The cooling subsystem consists of the S/EDHP/Solar/Electric Driven Heat Pump and its related equipment. Hardware design and development activity was initiated during this period for first cycle hardware in both the 3-ton and 10-ton unit sizes. An updated S/EDHP schematic is shown in Figure 2.3-21. The changes from the schematic shown in our proposal are as follows:

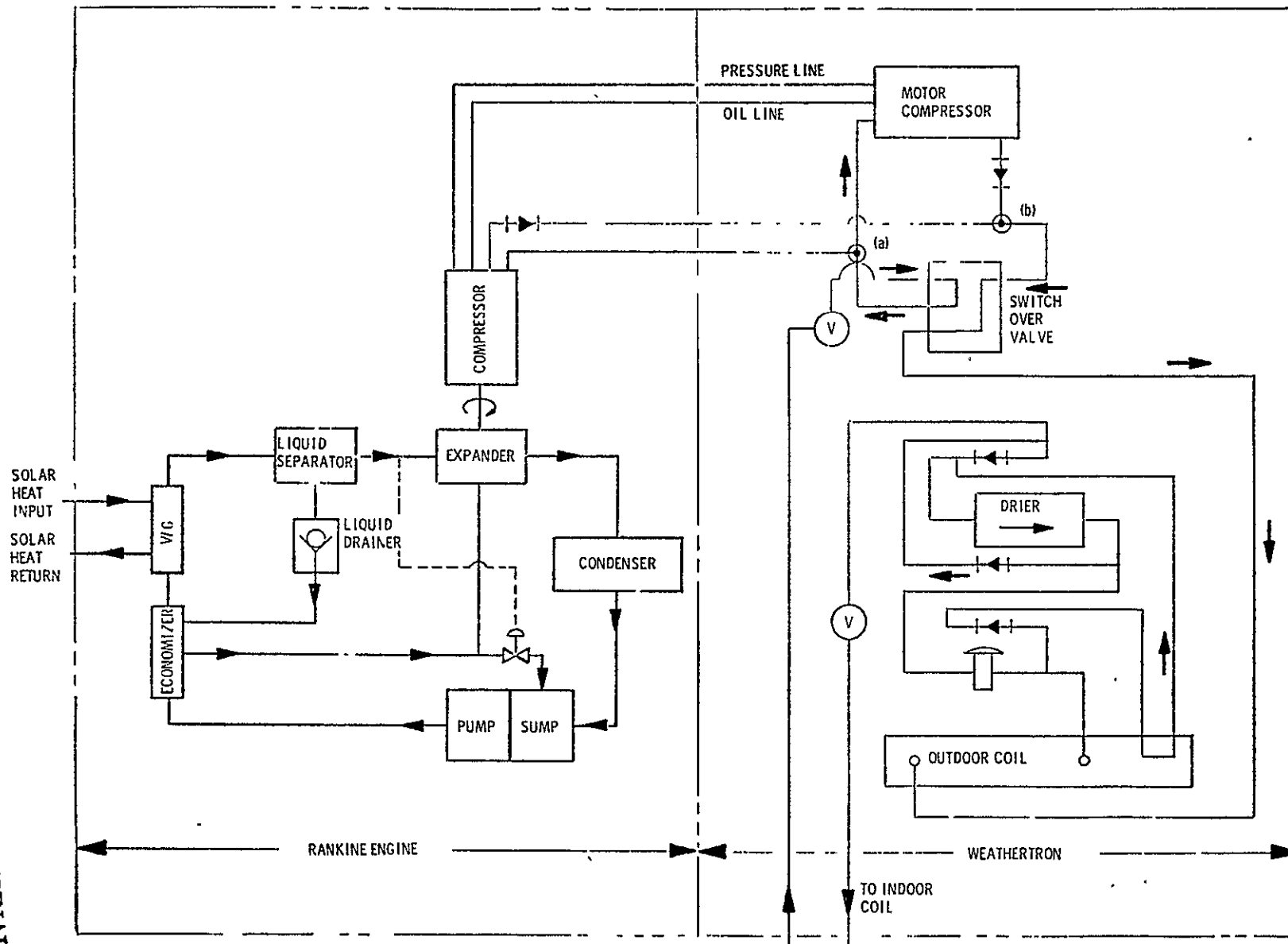


Figure 2.3-21. Schematic Diagram of S/EDHP (Cooling Mode)

1. Added an economizer to the Rankine engine loop
2. Eliminated the heat exchanger for DHW usage of waste heat from the Rankine engine loop

The electric driven heat pump part of the schematic has not changed.

The addition of an economizer to the Rankine engine loop is related to the vapor generator performance. Analytical predictions of vapor generator (V/G) performance indicated an appreciable size/cost penalty to design a V/G to deliver 100% quality fluid. As a result, the vapor generator will be designed for some limited vapor quality percentage. With vapor quality limited at design point an appreciable amount of thermal energy becomes available in the liquid phase leaving the liquid separator. Utilization of the liquid phase thermal energy for preheating the vapor generator fluid becomes worth while, therefore, the addition of an economizer to the loop is warranted.

The second change listed, removed the domestic hot water (DHW) heat exchanger from the Rankine engine loop. This change resulted from the systems analysis output as discussed in the previous section and from some very practical limitations. The application of instantaneous thermal loads to the Rankine engine loop with the use of a DHW heat exchanger is undesirable.

Elimination of the instantaneous thermal loads would require additional hardware, such as a heat exchanger/accumulator which would increase product cost and reduce system reliability and cycle efficiency. Therefore, the DHW HX was removed from the system.

2.3.2.10.1 Working Fluid Selection

Fluid selection considerations are best shown in the Pressure-Enthalpy Diagram of Figure 2.3-22. The LTR cycle is superimposed on the P-h diagram for R-11. Point ① of Figure 2.3-22 indicates the state of the freon fluid entering the boiler.

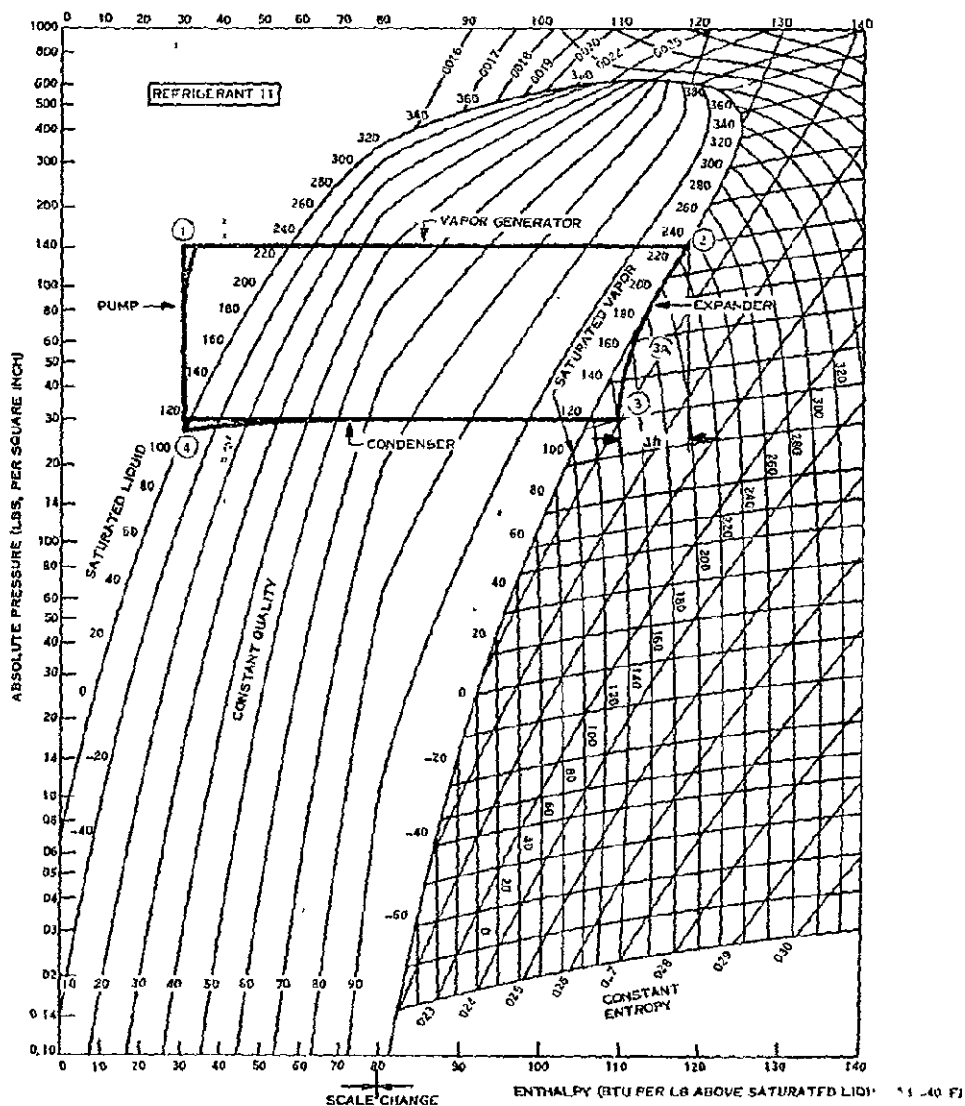


Figure 2.3-22. LTR Fluid Selection

At point ② the freon is vaporized and enters the expander at the saturated vapor line or some slight superheated condition. From ② to ③ the saturated vapor is expanded to the condensing pressure. If the expansion process were isentropic and 100% efficient, i.e., the expansion ratio required from P_2 to P_3 is fully achieved, point three would be at the intersection of the saturated vapor line and the condensing pressure. In reality, point ③ is somewhere near the point shown and the available Δh is as indicated. Should the achieved expansion ratio be limited to a point such as ③a, the available Δh is further reduced as is the power output.

From point ③ to point ④ condensation of the expanded vapor takes place through a heat exchanger to ambient temperature. For a given design point (day), little choice is available for changing the condensing temperature. Point ④ is critical in that we must assure a liquid fluid state point for pumping up to the boiler inlet state at point ①. Subcooling the fluid to insure liquid state pumping must be sufficient to assure pump operation even at low ambient test conditions, i.e., lower condensing temperatures.

The properties of interest for fluid evaluation are listed across the top of Table 2.3-4. The fluids evaluated are listed in column 1 of the same table. Screening of the fluids resulted in eliminating all except the R-11 or R114 for consideration. Excessive working pressure of components especially in the condensor as shown in column 5 of Table 2.3-4 eliminated R22, R12 and R-502. A critical temperature (column 2, Table 2.3-4) near the vapor generator operating range eliminated the same fluids as listed above. The reason being when operating near the top dome of the P/h curves results in decreasing values of Δh thereby reducing capacity.

Table 2.3-4. LTR Fluid Selection

1	2	3	4	5	6
FLUID	CRITICAL TEMP (°F)	ABS PRESSURE @ T CRITICAL (PSIA)	ABS PRESSURE @ 230°F (PSIA)	ABS PRESSURE @ 110°F (PSIA)	EXPANSION RATIO 230/110°F
R11	399.4	639.5	146.1	27.89	5.24
R114	294.3	480	247.9	53.782	4.61
R22	204.8	721.9	—	241.04	230 > T CRIT
R-12	233.6	596.9	577.0	151.11	3.82
R-502	179.9	591.00	—	262.61	230 > T CRIT
R113	417.4	500.0	81.31	12.76	6.37

A sub-atmospheric pressure at condensing temperatures of interest, as shown in column 5 of Table 2.3-4 resulted in the elimination of R113. The resulting choice of working fluid remained between R11 and R114. Over 2000 hours of operating experience with R-11 in an engineering unit resulted in choosing this fluid for our cycle.

2.3.2.10.2 Design State Point Schematics

The state point schematics for both the 3 and 10 ton LTR loops at the design point are shown in figures 2.3-23 and 2.3-24 respectively. The first cycle (development) hardware is being sized to meet these requirements. Note that the mass flowrates at the design points of the schematic are different values in the liquid line (entrance to the economizer) and the vapor line (at the entrance to the vapor generator). This difference in design flowrates is a result of vapor quality out of the vapor generator as previously discussed.

ORIGINAL PAGE IS
OF POOR QUALITY

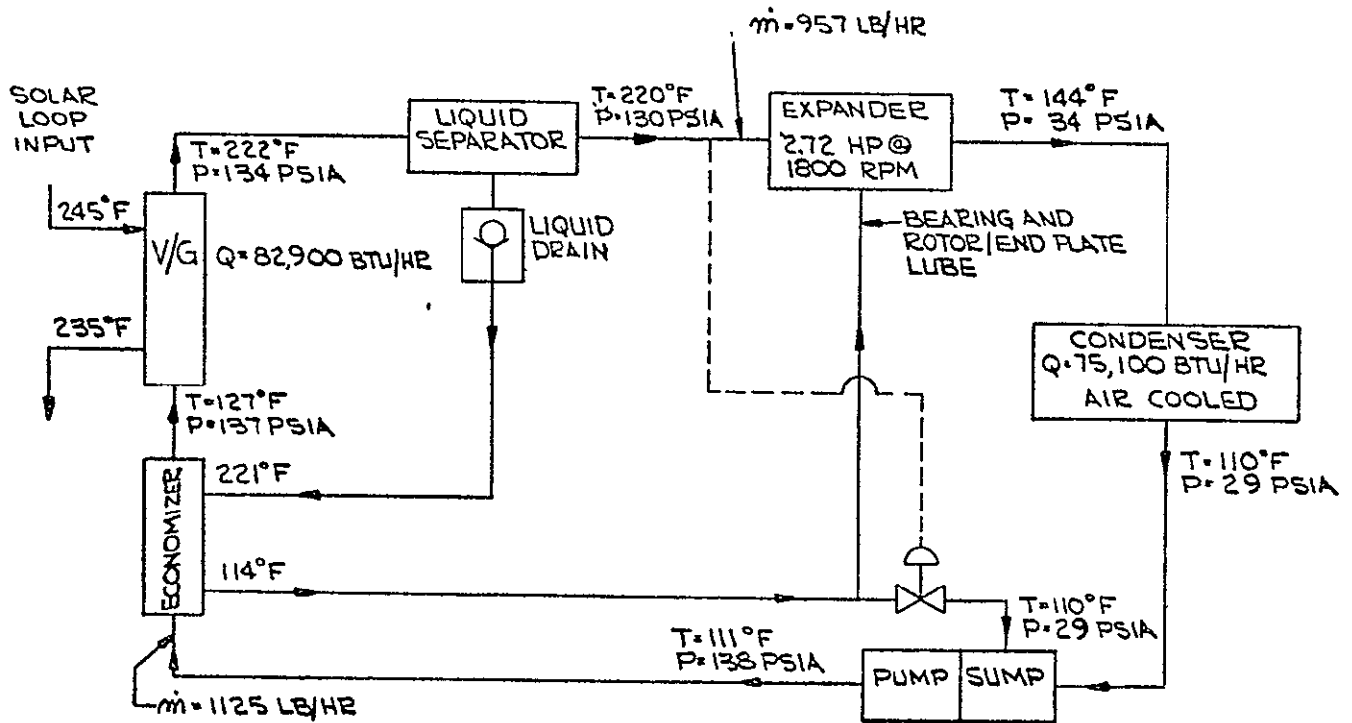


Figure 2.3-23. Three Ton LTR Loop Schematic (95°F Day)

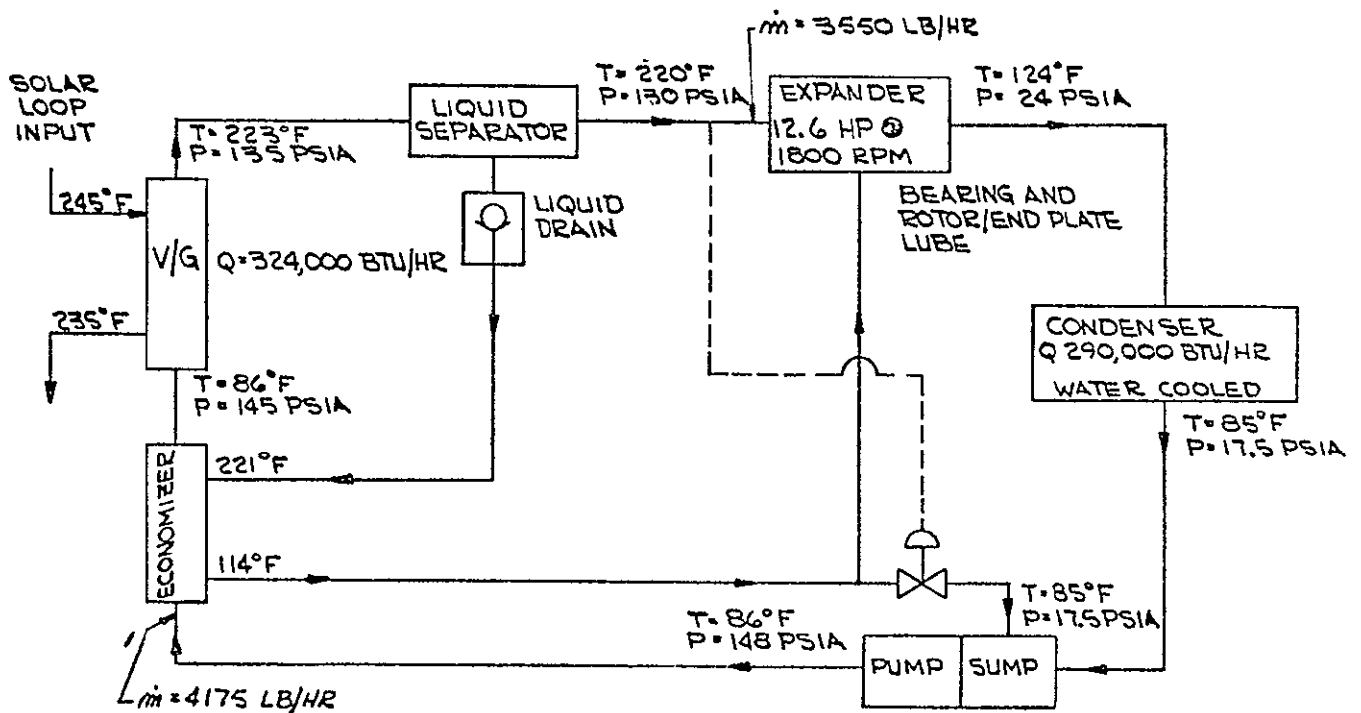


Figure 2.3-24. Ten Ton LTR Loop Schematic (95°F Day)

ORIGINAL PAGE IS
OF POOR QUALITY

2.3.2.10.3 Configurations

A layout of the 3 Ton S/EDHP 1st cycle hardware is shown in Figure 2.3-25 with a three dimensional view in Figure 2.3-26. Alternative configurations for the 10 ton S/EDHP are shown in Figures 2.3-27 thru 2.3-29. The first cycle (developmental) configuration selected is that shown in Figure 2.3-27. The alternate configurations of Figures 2.3-28 and 2.3-29 are shown to dramatize the size penalty incurred with the choice of airside condensing for the LTR loop.

2.3.2.10.4 S/EDHP Performance Curves

Preliminary performance curves as shown in Figures 2.3-30 thru 2.3-34, they are the combined results of two computer models with compressor performance test results. One model utilized the GE - CR & D heat pump performance predictions as shown in Figure 2.3-30. This mapping includes GE-CACPD compressor test results in the program. The second model is a Rankine engine computer code which was developed for the SHAC program with preliminary results as shown in Figure 2.3-31. Operating matched points for the two cycle (i.e., LTR/HP) are shown as circled intersections on Figure 2.3-32. From the data on Figure 2.3-32 a plot of cooling capacity versus T_{ambient} is generated. See Figure 2.3-33. Some speed limitations on the expander and compressor operation further limit the operating footprint reference Figure 2.3-34. Translating the Rankine engine/heat pump performance from speed to capacity results in the preliminary performance map of Figure 2.3-35.

A summary matrix of the hardware usage for the first cycle heat pump configuration is defined in Table 2.3-5.

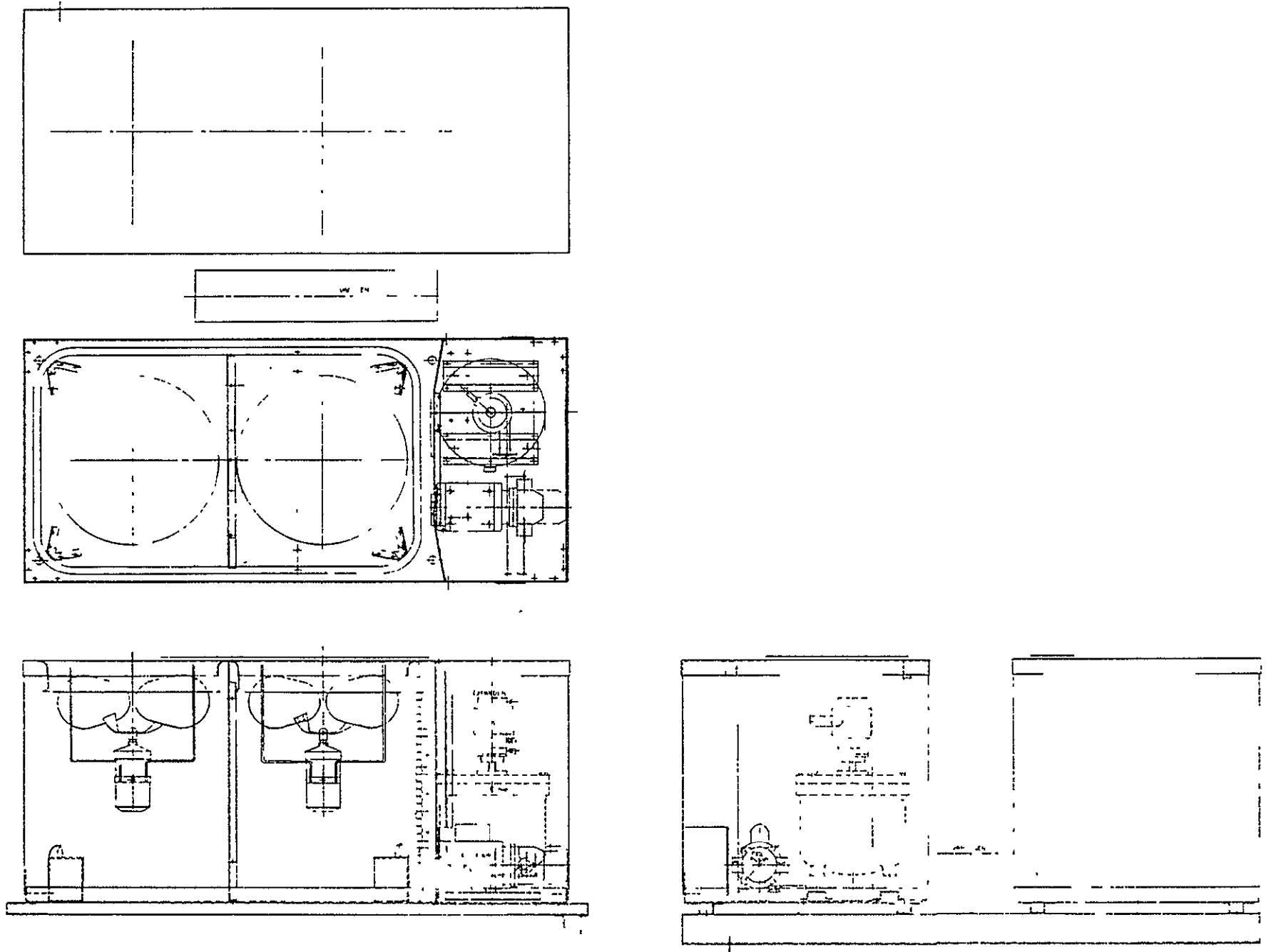


Figure 2.3-25. Three Ton S/EDHP Air Cooled (SF) Layout

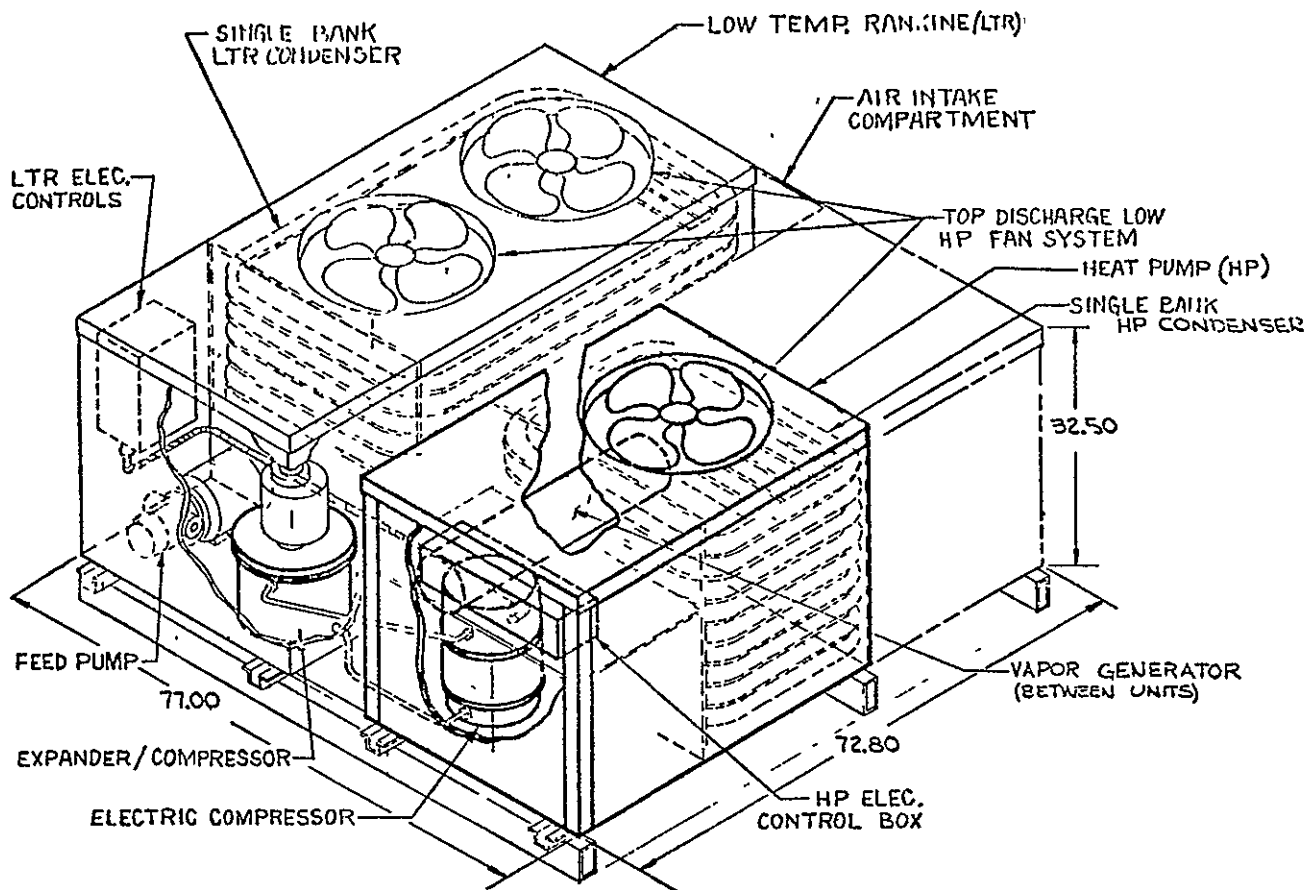


Figure 2.3-26. Three Ton S/EDHP Air Cooled (SF)

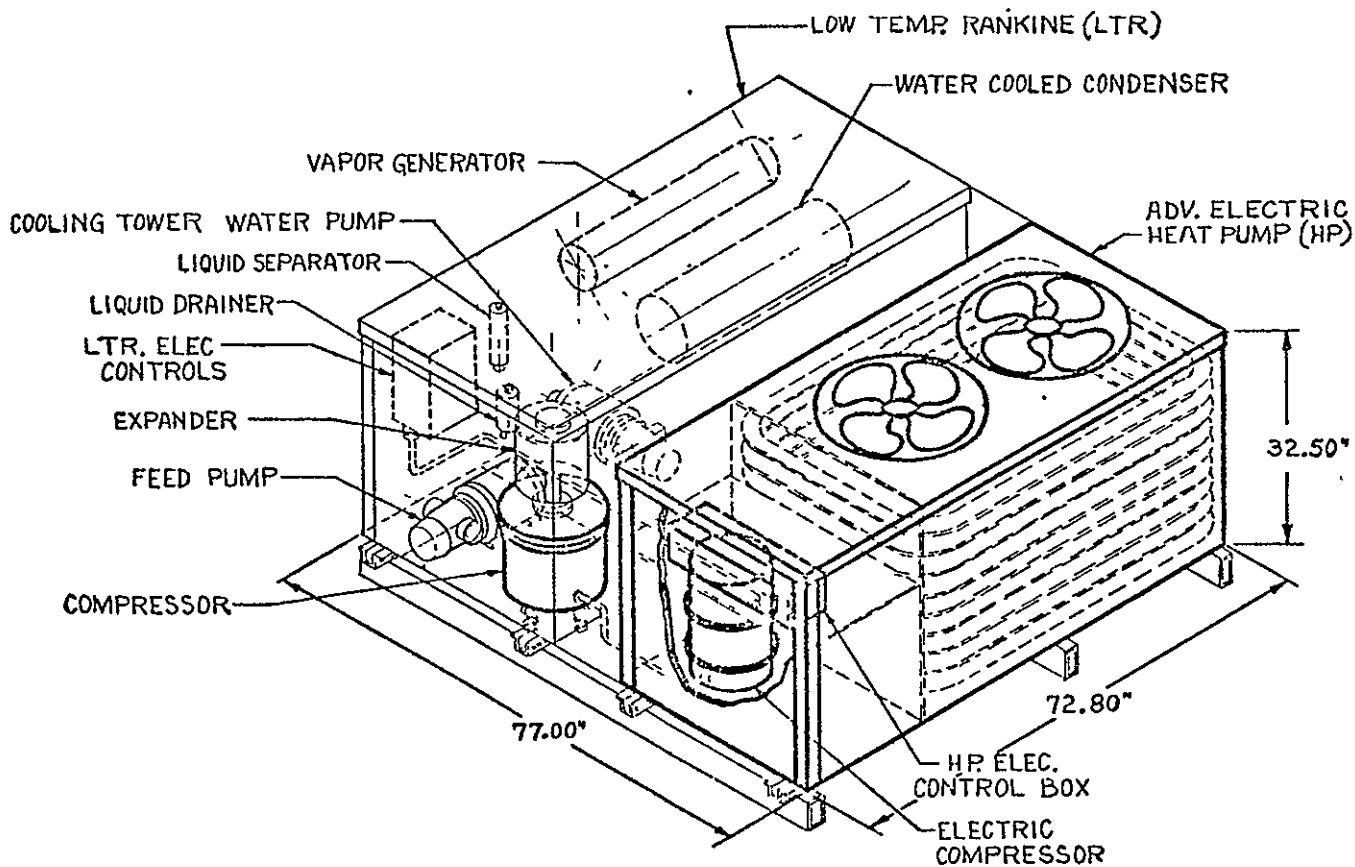


Figure 2.3-27. Ten Ton (Water Cooled) S/EDHP

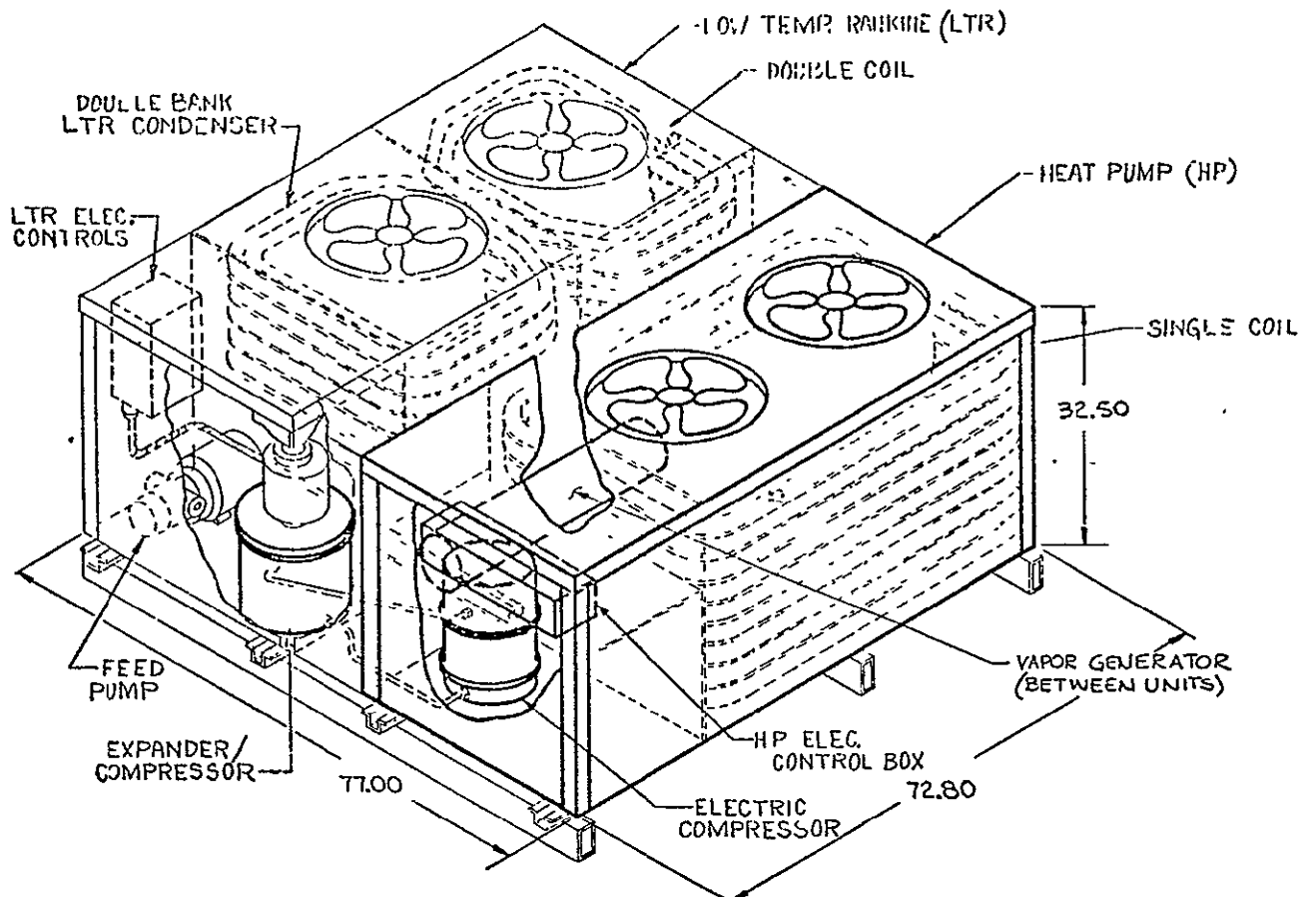


Figure 2.3-28. Ten Ton S/EDHP Air Cooled (MF/Com)

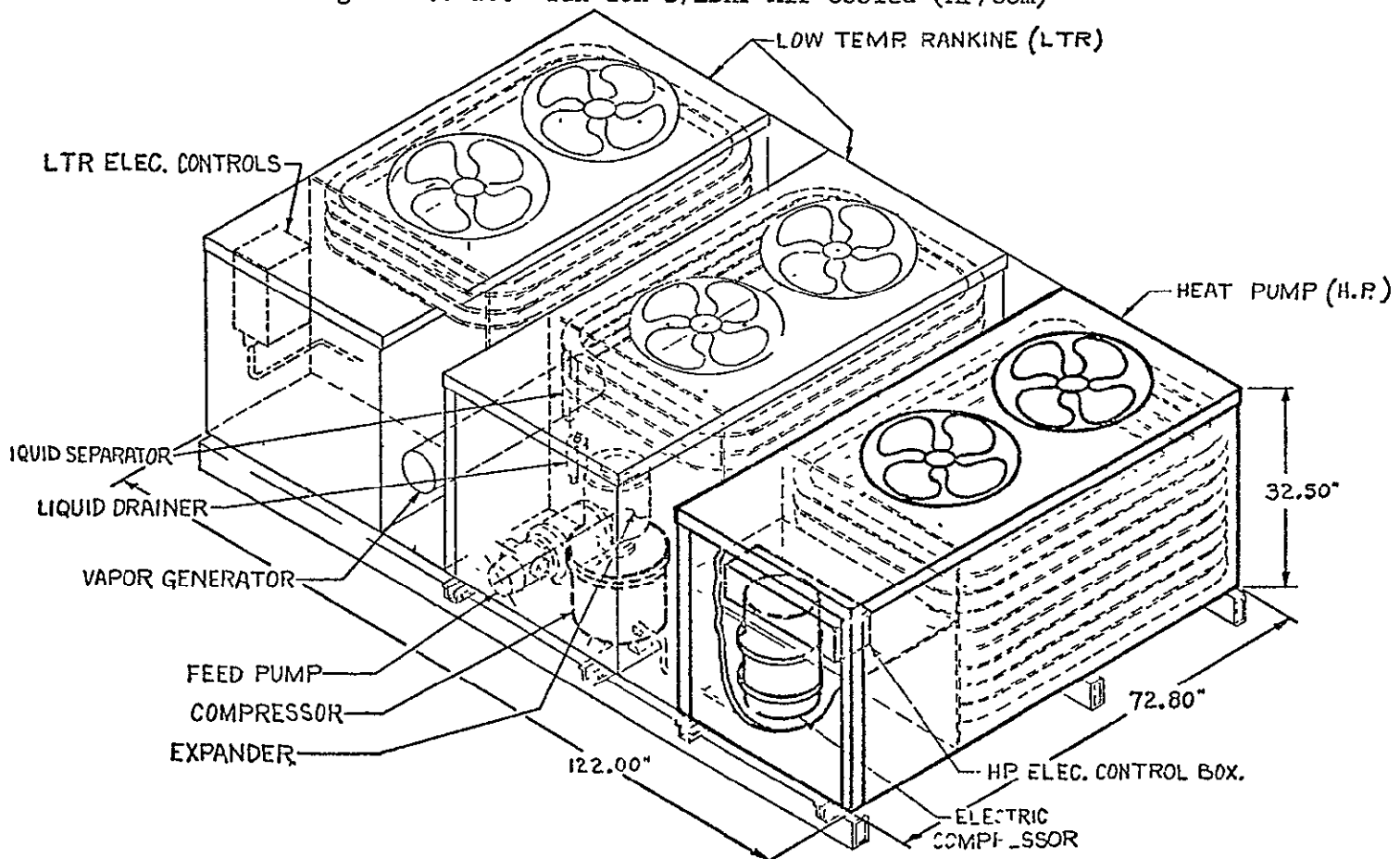


Figure 2.3-29. Ten Ton (Air Cooled) S/EDHP

Figure 2.3-30. Heat Pump Performance and Requirements

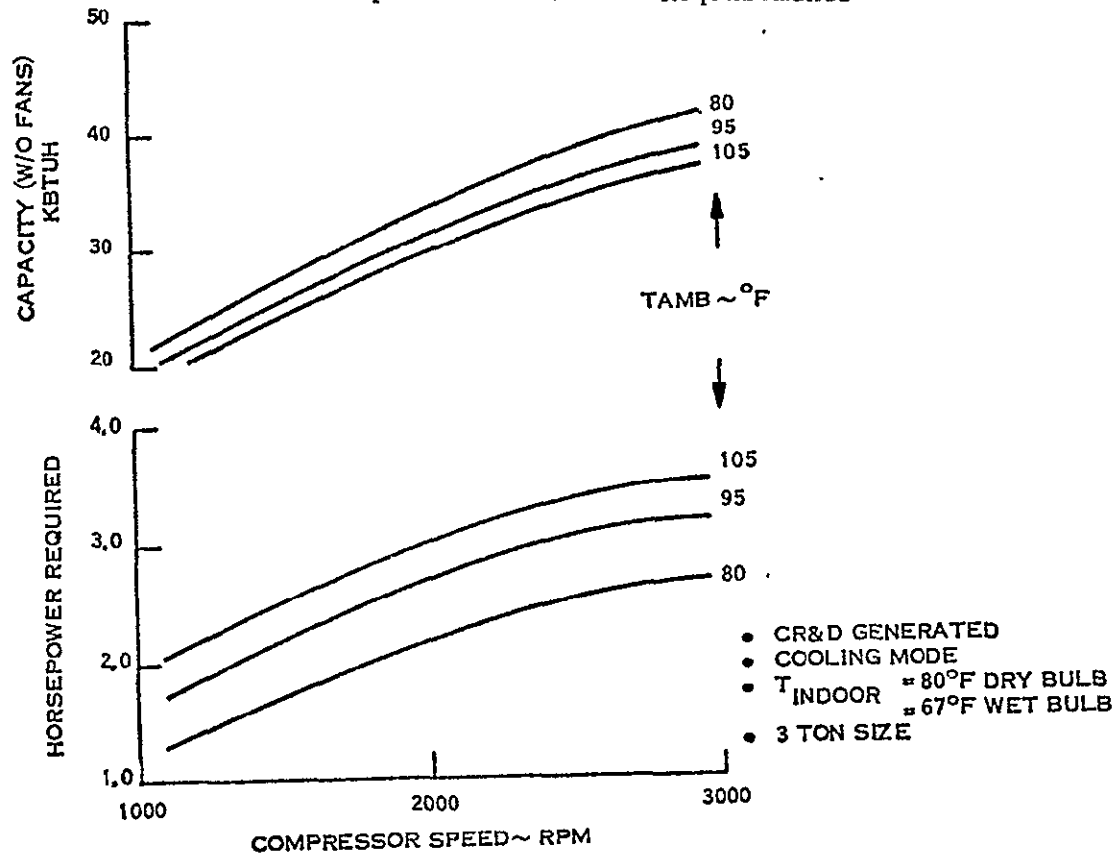


Figure 2.3-30 Heat Pump Performance and Requirements

- TAMB = 95°F
- 3 TON SIZE

EFFECT OF SOLAR FLUID INLET TEMP.

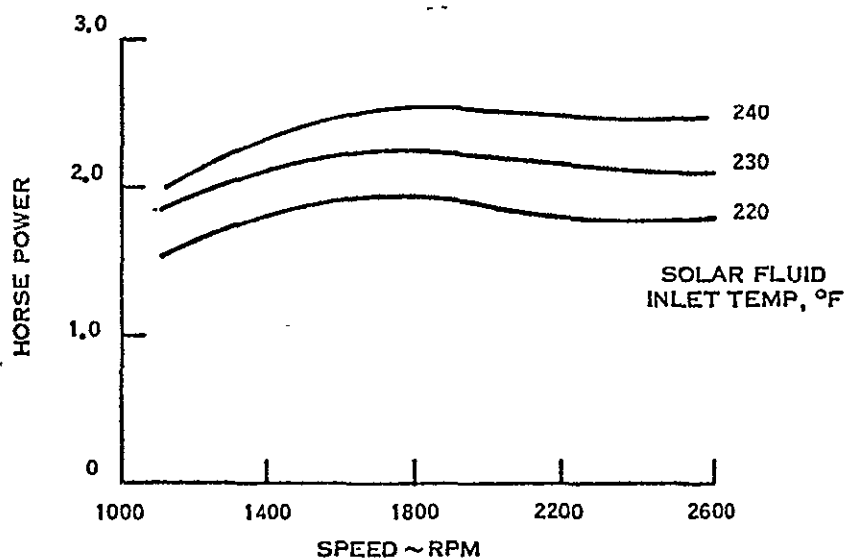


Figure 2.3-31 LTR Off Design Performance

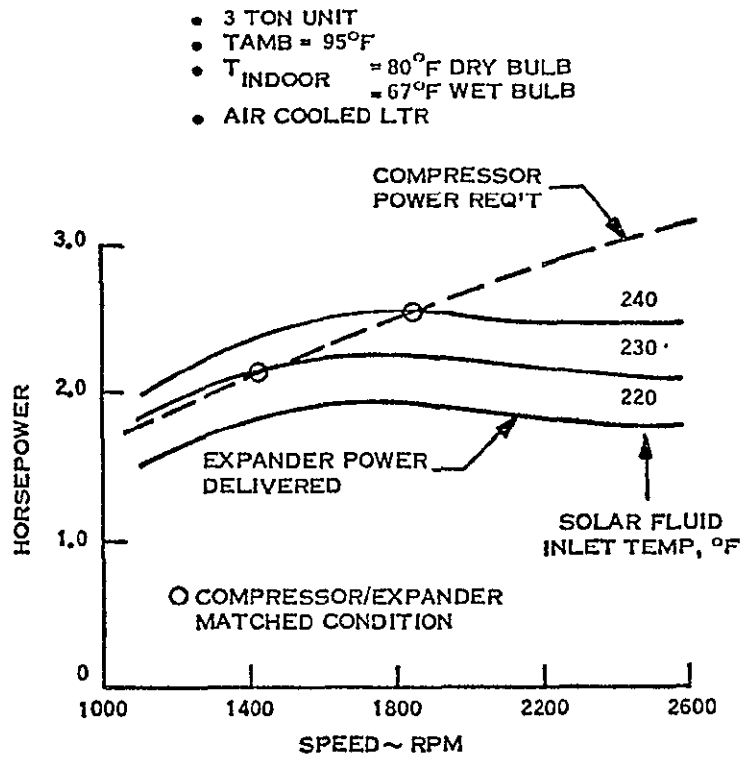
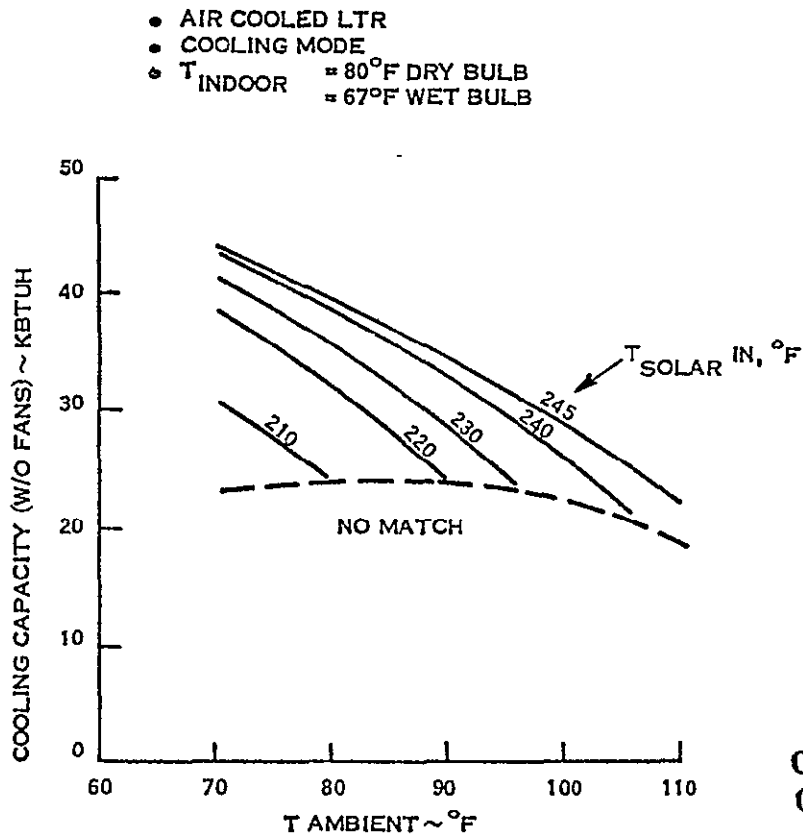


Figure 2.3-32. LTR/HP Matched Operation



ORIGINAL PAGE IS
OF POOR QUALITY

Figure 2.3-33. Three Ton LTR/HP Matched Operating Points

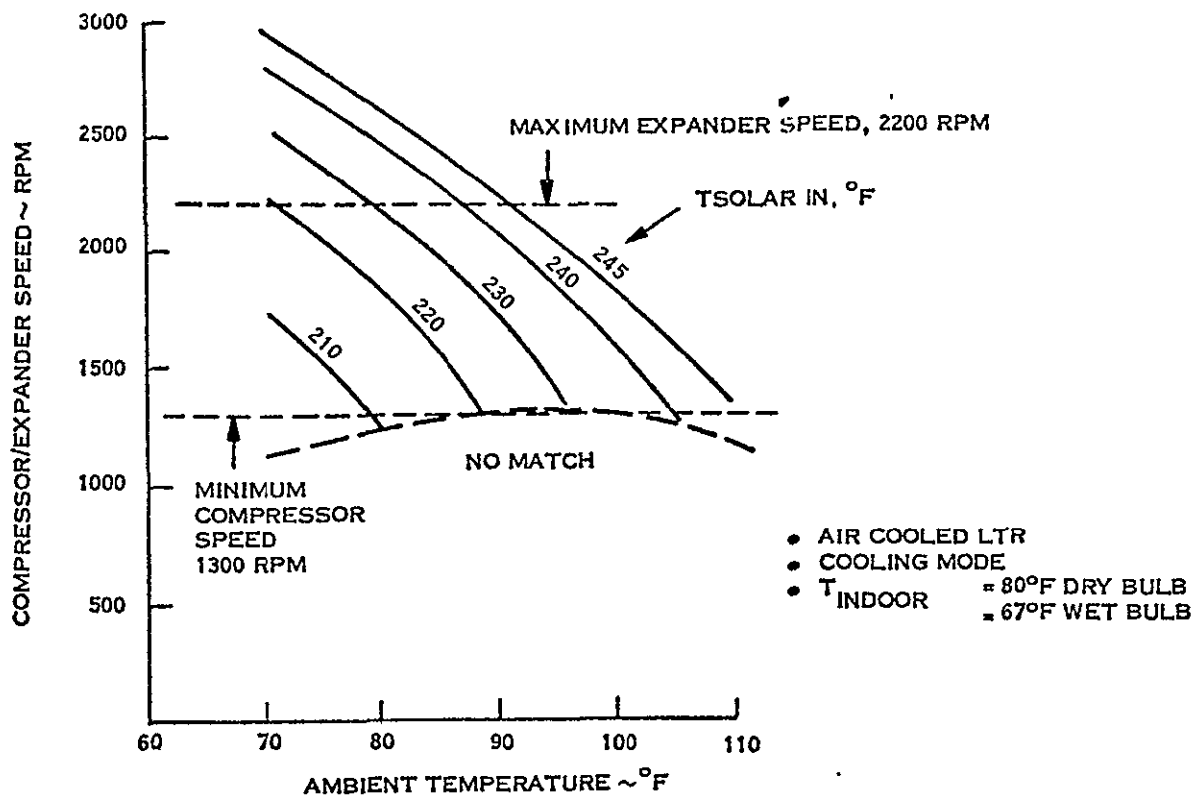


Figure 2.3-34. Three Ton LTR/HP Matched Operating Speed

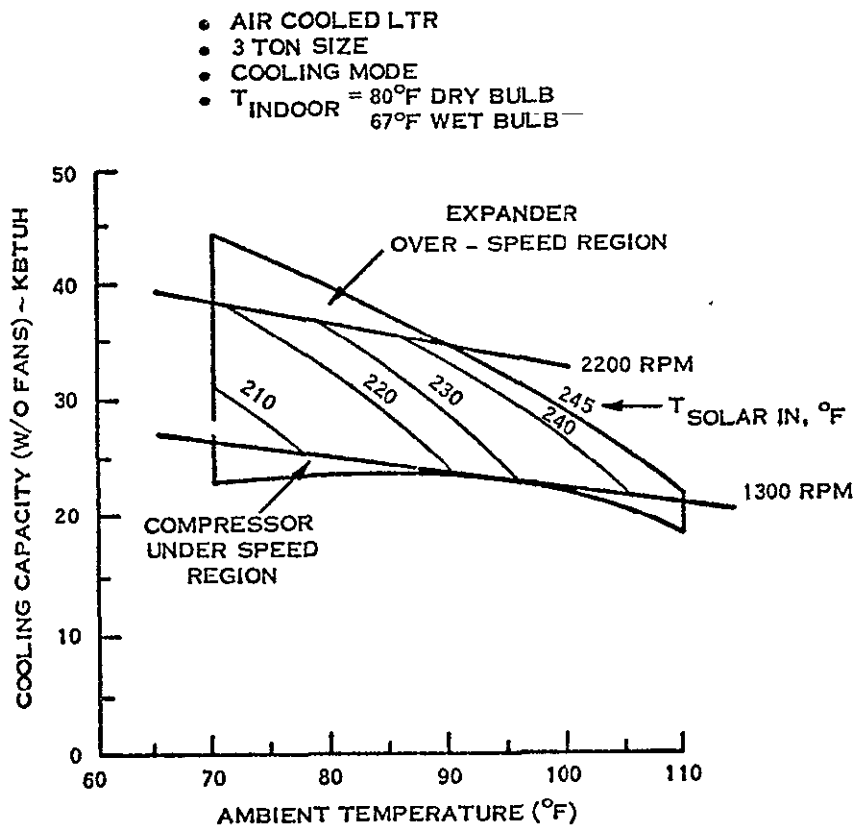


Figure 2.3-35. Effect of Speed Limitations on Matched Operation Map

Table 2.3-5. 1st Cycle Baseline Heat Pump Hardware

NOMINAL RATING	SF/MF	MF/COMM
	3 TON	10 TON
• INDOOR COIL	60,000 BTUH	120,000 BTUH
• OUTDOOR COIL	60,000 BTUH	120,000 BTUH
• INDOOR FAN		
• MECHANICAL	1,200 CFM	2,700 CFM
• ELECTRICAL	1,200 CFM	4,000 CFM
• OUTDOOR FAN	4,000 CFM	8,000 CFM
• COMPRESSOR		
• MECHANICAL	CT 64 KM	CT 160 KW
• ELECTRICAL	CT 80 KP	CT 125 HU
• CAPACITY		
• MECHANICAL	2 1/2 TON	7 TON
• ELECTRICAL	3 TON	10 TON

2.3.2.10.5 Solar Driven Compressor

The solar driven compressor is being developed as a modification to the standard Weathertron[®] hermetic compressor. The modifications required are as follows:

1. Addition of a Shaft Seal
2. Lubrication of seal
3. Change from internal to external spring mounting
4. Expander driven vs. electric motor driven

Some of the basic hermetic motor characteristics retained in the solar driven version are:

1. Reciprocating

ORIGINAL PAGE IS
OF POOR QUALITY

2. Vertical shaft
3. Two main journal bearings
4. Centrifugal oil pump
5. Low loss valves
6. Internal mufflers.

The open shaft compressor modifications are shown in Figure 2.3-36.

2.3.2.10.6 Future Work (TRADES)

The following activities are planned using the performance models:

- . Off-design operation of 10 Ton unit
- . Performance mapping of 10 Ton unit
- . Performance predictions with water cooled condensers.

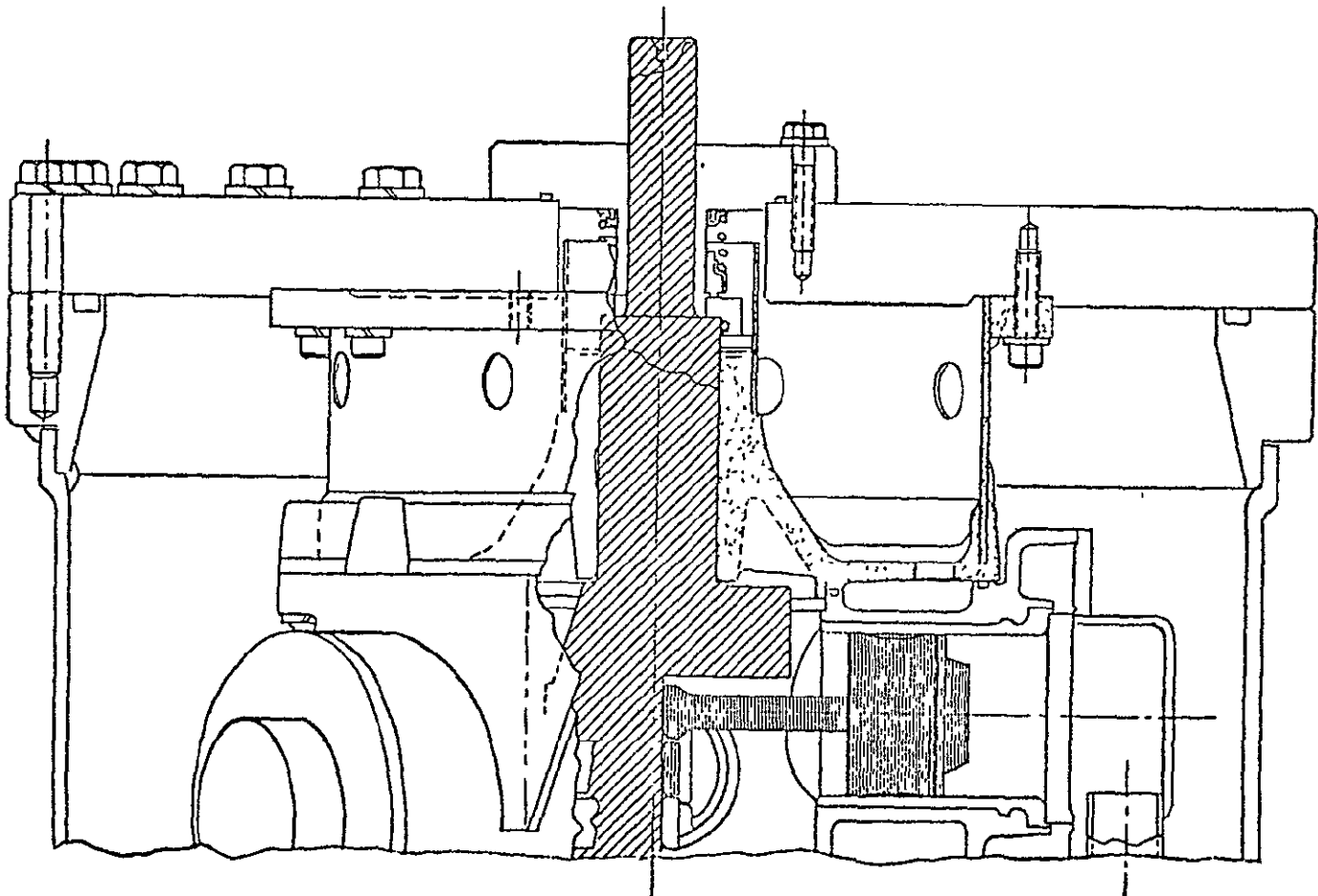


Figure 2.3-36. Open-Shaft Compressor
4-86

2.4 TEST (WBS 1.2.3)

Test planning is proceeding at all levels of component, Sub-System and System for the Heating only and the Heating and Cooling configurations.

Test plans are completed for component, development of several facets of the solar collectors (refer to paragraph 2.3.1.1).

Test facilities are essentially in place for the heating system component testing. Modification of the outdoor solar collector loop is proceeding and will provide high temperature and high pressure test capability much in excess of the temperature and pressure requirements for the SHAC program. A schematic of the modified solar collector test loop is shown in Figure 2.4-10.

Component testing of the control system is proceeding. Outdoor testing of the special solar insolation sensor was performed and a data plot (Figure 2.4-2) is included showing the excellent correlation of the Ll4Hl Photodiode with a Model 8-48 Epply Pyranometer.

Refurbishment of the existing test facilities for the Low Temperature Rankine (LTR) is proceeding on schedule. Two complete and separate test loops, one 3 Ton size and one 10 Ton size will be available on a full time basis to support the development testing of the LTR throughout the life of the program. Figure 2.4-3 is a typical schematic for the LTR test loop. Incorporated in the test loop design are sufficient disconnects to allow test flexibility for replacing components or substituting components as required. A by-pass loop is provided around the expander to allow testing of other LTR components (vapor generator, liquid separator, pumps, etc.) when it is convenient or desirable to do so.

The controlled environment System Test Facility for the 3 Ton size (Figure 2.4-4) is in the construction phase and is ahead of schedule to support the SHAC program.

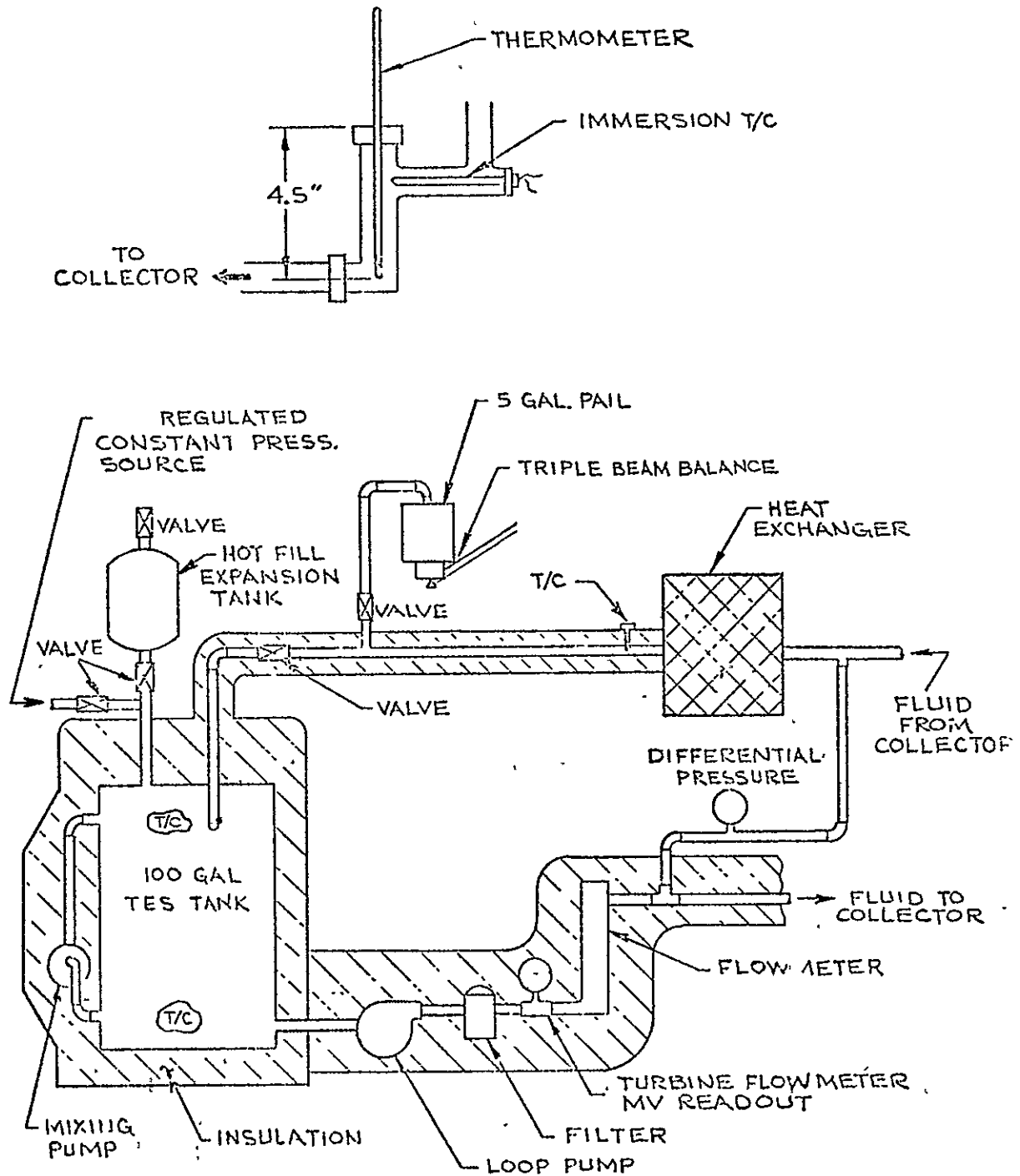


Figure 2.4-1. Solar Collector Test Facility

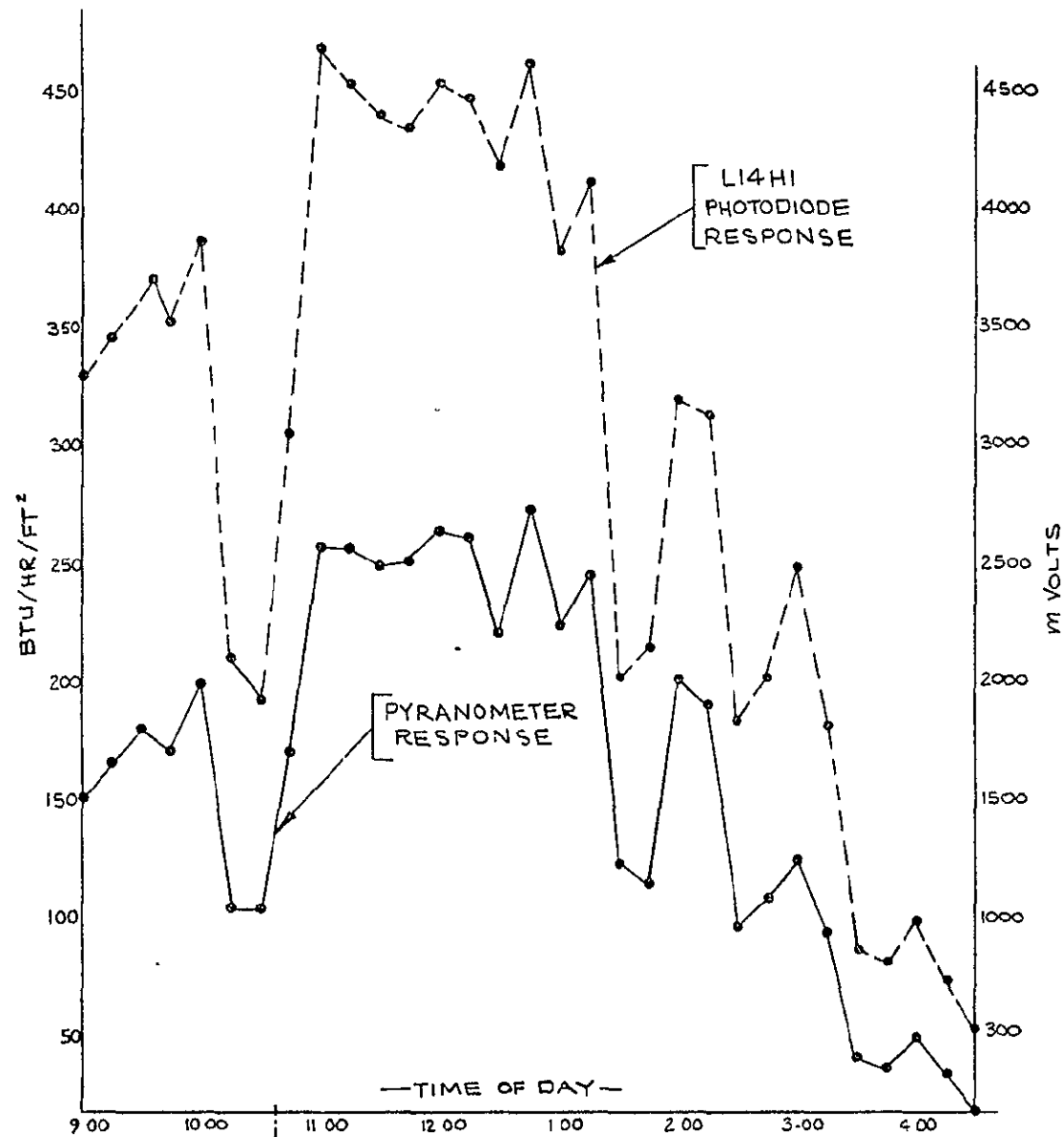


Figure 2.4-2. Solar Insolation Sensor Data

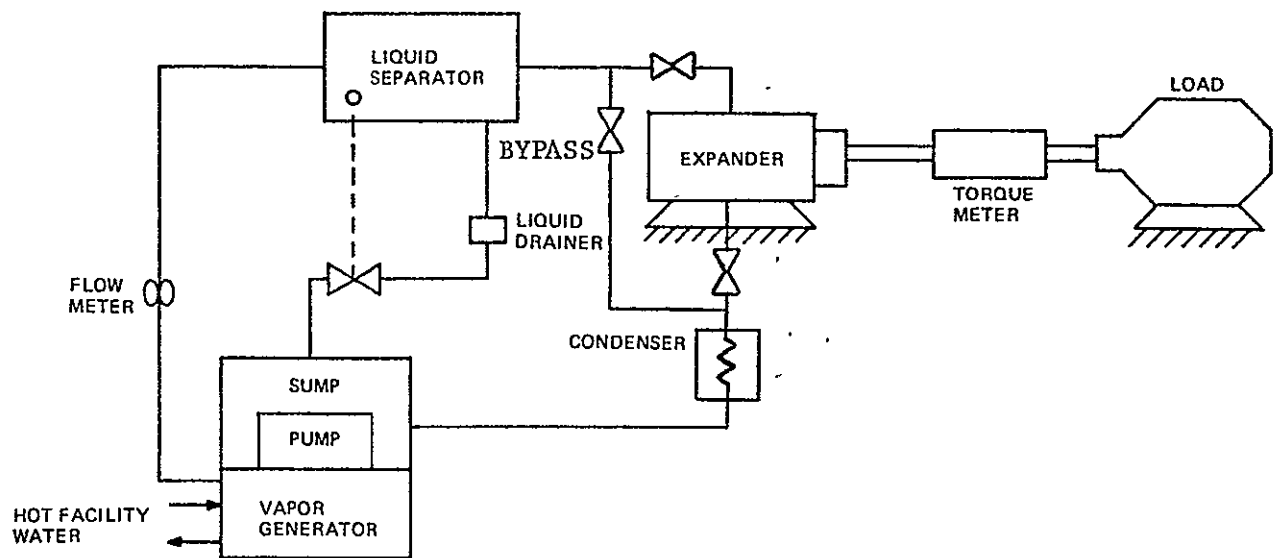


Figure 2.4-3. LTR Test Loop

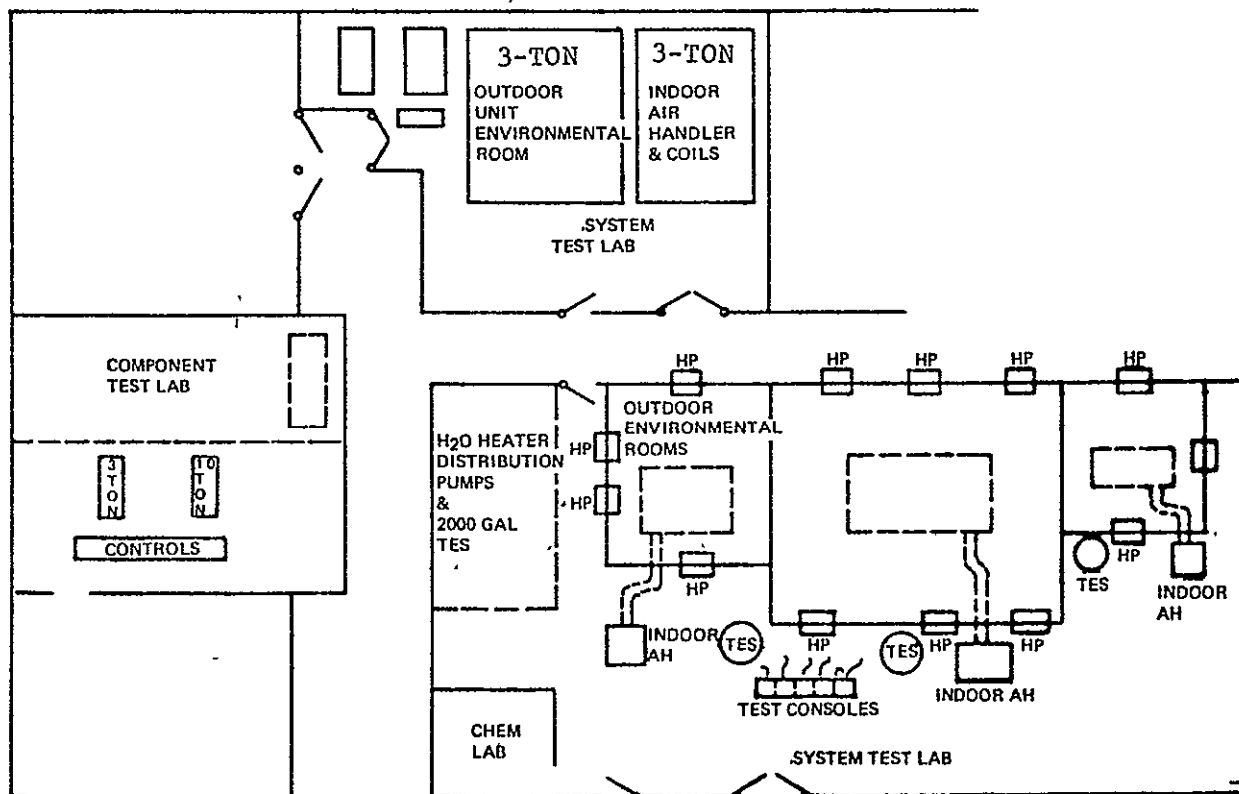


Figure 2.4-4. System Test Facility (3-Ton)

SECTION 3

DELIVERABLE HARDWARE

(Not applicable)